Cunninghamia

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Cunninghamia

A journal of plant ecology for eastern Australia

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Allan Cunningham, botanist and explorer (1791–1839)

Cover: The entrance to Sydney Harbour, looking from South Head with heath perched above its sandstone cliffs, across to North Head, the largest Sydney Harbour National Park precinct. Photo Jaime Plaza

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Scientific Editor
Doug Benson
Royal Botanic Gardens,
Mrs Macquaries Road, Sydney, Australia 2000.
Email: doug.benson@rbgsyd.nsw.gov.au

Scientific Editorial Committee
Brett Summerell, Bob Makinson, Tony Auld.

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Julia Sideris

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SHORT COMMUNICATION

On the ecology, distribution and conservation status of *Vittadinia blackii* (Asteraceae) in Australia

I.R.K. Sluiter and K.R Sluiter[1]

Centre for Environmental Management, School of Science and Engineering, University of Ballarat, Mt. Helen, VIC 3353, AUSTRALIA
[1]Mallee Catchment Management Authority, Mildura, VIC 3500, AUSTRALIA

Abstract: Distribution records of *Vittadinia blackii* (family Asteraceae) across southern Australia show the species has a strong and moderately common presence across a broad range of climate zones and sites in South Australia, but a much more restricted occurrence in other mainland state's. Using the IUCN criteria, adopted by the separate state regulatory authorities vested with listing threatened species, *Vittadinia blackii* is considered to be not threatened in South Australia, but endangered in Western Australia, Victoria and New South Wales.

***Cunninghamia* (2011) 12(1): 1–5**

Introduction

Vittadinia blackii N. Burb. (family Asteraceae) is a compact perennial sub-shrub growing to approximately 20–40cm high (Burbidge 1969) (Figure 1). It is readily distinguishable in the field from other taxa within the genus by its narrow, dark green grooved leaves (the only species with similar leaf type – *Vittadinia muelleri* – occurs in the dry sub-humid climates of Tasmania and the eastern Australian mainland from East Gippsland in Victoria through New South Wales into southern Queensland, with no over-lapping range with *Vittadinia blackii*). South Australia is the stronghold for *Vittadinia blackii* in southern Australia, but the species occurs across differing climatic zones with major disjunctions between populations in other states, particularly Western Australia. This paper assumes the taxonomy for *Vittadinia blackii* is not in question. Here the ecology and distribution of *Vittadinia blackii* and its current conservation status across four states is discussed.

Ecology of *Vittadinia*

With the exception of *Vittadinia australis* and *Vittadinia simulans* (which occur in New Zealand and New Caledonia respectively), *Vittadinia* is primarily an Australian genus. It comprises two sub-genera *Vittadinia* and *Peripleura* containing 20 and 9 species respectively, mostly restricted to southern and central Australia (Burbidge 1982). Two other closely related genera, *Eurybiopsis* and *Camptacra*, are found in northern Australia (Burbidge 1982). Detailed accounts of the ecology and/or seed biology of representatives of the genus are restricted to *Vittadinia muelleri* (Willis & Groves 1991; Trémont 1995) and *Vittadinia cuneata* (Facelli *et al.* 2005). In a study of the phenology of six understorey herbs

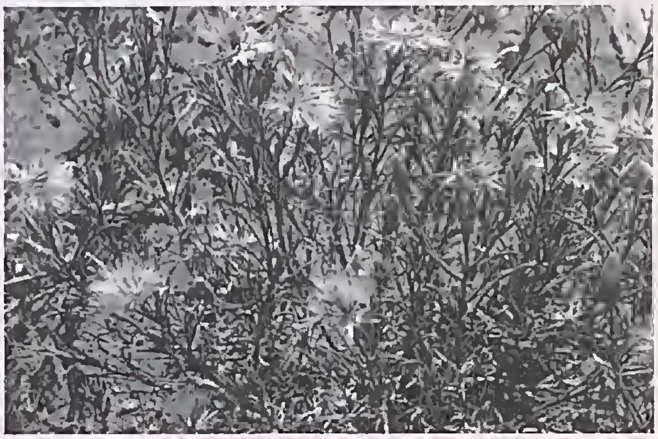

Fig.1. *Vittadinia blackii* growing on a mine rehabilitation site 40 km west of Pooncarie (far southwest New South Wales). Photograph Ian Sluiter 06/05/2010.

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and short-lived perennials from a derived native grassland on the New South Wales Northern Tablelands (Trémont 1995), *Vittadinia muelleri* was found to initiate growth in the coldest months of the year (July) and to commence flowering in late October and fruiting in December with release of fruit maintained in some plants until May – June of the following year. Willis and Groves (1991) found *Vittadinia muelleri* exhibited a wide germination tolerance to varying light and temperature regimes, but noted that cold stratification also promoted germination.

Facelli *et al.* (2005) studied the ability of *Vittadinia cuneata* and four other taxa to persist in the soil seed store of an arid rangeland dominated *Acacia papyrocarpa* with an understorey of *Maireana sedifolia* and *Atriplex vesicaria. Vittadinia cuneata* was found to have 70% of seed still present after two years of burial within the soil, a result comparable with three of the other indigenous taxa studied. The studied concluded that most annual and short-lived perennial ground flora taxa in this southern Australian arid rangeland property were obligate winter annuals (Baskin & Baskin 1993) having mechanisms that prevented germination during the hottest months even when summer rainfall maybe plentiful; a strategy apparently deployed to avoid the inherent risk of desiccation after summer rainfall when water may evaporate too quickly for survival and effective plant growth (Facelli *et al.* 2005).

At the risk of applying broad brush ecology across other members of the genus *Vittadinia*, the published accounts of winter – spring emergence and growth, and persistent summer flowering and autumn fruiting are in accordance with the author's observations of other *Vittadinia* species including *Vittadinia cervicularis, V. dissecta, V. gracilis, V. cuneata, V. australasica, V. sulcata* and *V. pterochaeta* from semi-arid areas of northwest Victoria and southwest New South Wales.

There are no specific published accounts of the ecology of *Vittadinia blackii*. Notes on herbarium records suggest the species occurs across a wide variety of habitats including fire-prone mallee and hummock grass habitats, to woodland types with sandy soils and skeletal soil types that seldom burn. Jessop and Toelken (1986) suggest *Vittadinia blackii* grows "in woodland, mallee and cleared land on clay or limestone" in South Australia. In the Flinders Ranges, collector's notes also suggest a preference for rocky hillsides. Collection notes from a number of records from the Western Australian sites in the early 1990s indicate a preference for red, sandy clay loam soils, sometimes in depressions or associated with *Triodia* sp. (Hummock Grass) or *Eucalyptus salubris* (Gimlet). In western Victoria, collections from Wail were from a *Allocasuarina leuhmannii* (Buloke) – *Eucalyptus leucoxylon* (Yellow Gum) Woodland and at Pine Plains from *Callitris gracilis* subsp. *murrayensis* (Pine) – *Allocasuarina leuhmannii* Buloke Woodland. The remaining subpopulation in Victoria, in Bronzewing Flora and Fauna Reserve, was from a sandy swale under mallee. In New South Wales, the site 80 km northwest of Balranald was from mallee, and the site at Round Hill Nature Reserve is likely to be mallee. At a recently discovered site at the Ginkgo Mine 40 km west of Pooncarie, *Vittadinia blackii* was found growing in a mining rehabilitation site where soil was stripped from remnant vegetation containing primarily *Casuarina pauper* (Belah) – *Alectryon oleifolius* subsp. *canescens* (Rosewood) Woodland.

Table 1: Number of herbarium specimens of *Vittadinia blackii* held by Australian herbaria, sorted by State of collection (some herbaria may hold duplicates)

Herbarium	WA	SA	NSW	VIC
State Herbarium of South Australia	1	148	2	1
Western Australian Herbarium	2			
National Herbarium Melbourne	8	15	2	4
National Herbarium Sydney		6	2	
National Herbarium Canberra	1	3	1	
Canberra Botanic Gardens		3		
Tasmanian Herbarium		2		
TOTAL	12	177	7	5

Distribution and conservation status of *Vittadinia blackii*

The conservation status of plant taxa occurring at the state or regional level follow the criteria outlined in IUCN (2001). Terms such as population and subpopulation follow definitions as outlined in that publication. The IUCN conservation status categories and criteria for listing, have, by-and-large received universal acceptance amongst Australian state conservation agencies vested with assigning conservation status and, hence, have been adopted in this paper. The distribution and extent of a species is an important component in assessing conservation status.

South Australia is the stronghold for *Vittadinia blackii* in southern Australia, with the majority of Herbarium collections (Figure 2, Table1); the species is not considered as rare or threatened in that State but in the adjoining southern mainland states, the distribution of the species is widespread but more sporadic, and the conservation status is less clear.

South Australia

Vittadinia blackii occurs at a wide range of locations in semi-arid to sub-humid areas across South Australia from areas with less than 200 mm rainfall up to 400–500 mm per.annum (Figure 3). There are even occasional occurrences in the Adelaide Hills where 800–1,000 mm of rainfall per annum is received. The majority of South Australian collections, come from the Flinders-Olary Block Bioregion and the Yorke Peninsula part of the Eyre-Yorke Block Bioregion, with fewer from the Murray-Darling Depression Bioregion and nearby bioregions. Occasional outliers near Lake Eyre South, Ceduna and the Lower Southeast of South Australia point to a distribution across arid, semi-arid and temperate (sub-humid) parts of the State. *Vittadinia blackii* is not listed as either rare or threatened in that State, and would not satisfy any of the IUCN criteria required for listing.

Western Australia

All known records of *Vittadinia blackii* in Western Australia occur over approximately 4,000 km² spread between Cape Arid National Park in the south, north to the Dundas Nature Reserve and west to Mt. Buraminya (except for an 1881 record from 3 km east-south-east of Eucla near the South Australian Border) (Table 2). Indeed all the records collected between 1990 and 2006 have come from a smaller (10 x 25 km = 250 km²) area 140 km northeast of Esperance, midway between the northwest corner of Cape Arid National Park and the southern edge of the Dundas Nature Reserve, near Mt. Buraminya. Notwithstanding relatively recent (1990–1992) collection notes by W. Archer, indicating the plant is common at collection sites within

Table 2: Herbarium specimens and records of *Vittadinia blackii* from southern Australian mainland states other than South Australia.

Herbarium No.	Locality	Lat.	Long.	Collector	Year	Notes
WESTERN AUSTRALIA						
See 'Notes'	~140km northeast of Esperance	32° 59'	123° 20'	Archer, W.R.	1990–1992	Five collections at MEL (MEL2018571A to MEL2018575A) and one at AD (AD99407177) and CANB (CANB471127) all by W.R. Archer between 1990 and 1992 from an area approximately 140km northeast of Esperance.
PERTH07517831	~140km northeast of Esperance	33° 10'	123° 20'	Edinger, D.J.	2006	
MEL1004481A	~140km northeast of Esperance	33° 27'	123° 28'	Brooks, S.	?pre 1900	
MEL30012A	~170 km east of Norseman	32° 00'	123° 25'	Brooks, S.	1886	
MEL1004514A	3 km east-south-east of Eucla	31° 43'	128° 52'	Oliver, J.	1881	
VICTORIA						
MEL2100277A	Wail State Forest,	36° 30'	142° 04'	Goods, M	2000	Growing in sandy clay loam with Buloke (*Allocasuarina luehmannii*) and Yellow Gum (*Eucalyptus leucoxylon*).
S01207–FIS	Wail State Forest	36° 30'	142° 05'	Dickens, M.J.	2000	
MEL2328634A	Bronzewing Flora & Fauna Res.	35° 12'	142° 21'	Macfarlane, J.N.	2007	In open sandy swale under mallee.
MEL30017A	Pine Plains, Wyperfeld N.P.	35° 25'	141° 55'	Dallachy, J.	pre 1900	
M31430–FIS	Pine Plains, Wyperfeld N.P.	35° 21'	141° 57'	Jaensch, S.	1993	Growing in a Pine (*Callitris gracilis* ssp. *murrayensis*) and Buloke (*Allocasuarina luehmannii*) Woodland
S23288–FIS	Pine Plains, Wyperfeld N.P.	35° 24'	141° 55'	Beauglehole, A.C.	1986	
1H0480–FIS	Pine Plains, Wyperfeld N.P.	35° 28'	141° 57'	Cheal, D.C.	1985	
MEL30010A	Near the Victorian and South Australian Border			Mueller, F.	pre 1900	
NEW SOUTH WALES						
NSW863000	Ginkgo Mineral Sands Mine ~40 km west of Pooncarie	33° 21'	142° 13'	Sluiter, I.R.K.	2010	Growing in minesite rehabilitation along with Bladder Saltbush (*Atriplex vesicaria*) and Bluebush (*Maireana* spp) species
NSW419518	Round Hill Nature Reserve	33° 05'	146° 21'	Hager, T.	1994	Linear *Vittadinia*
NSW573848	80km NW of Balranald	34° 03'	143° 01'	Mulham, W.E.	1970	Growing in Mallee; Also held at CANB (CANB648837)
MEL30016A	Interior of NSW	Unknown	Unknown	?Moore, C.	pre 1900	
MEL1004355B	Darling Desert	Unknown	Unknown	Unknown	pre 1900	

this area, the actual known extant distribution is extremely limited. The presence, however, of the species in this part of the state pre 1900 (Brooks – 2 collections), in the early 1990's (Archer – 7 collections) and in 2006 (Edinger – 1 collection) shows a reliable and apparently persistent history of occurrence.

The Western Australian Dept. of Environment and Conservation (DEC) currently list *Vittadinia blackii* as 'not threatened' in Western Australia. However with an extant distribution in Western Australia restricted to just 250 km, *Vittadinia blackii* satisfies IUCN 'Geographic Range' criteria B1a, B1b, B1c, B2a, B2b and B2c relating to 'extent of occurrence' and 'area of occupancy' respectively. In particular, the species is known from less than ten extant sites over an area of < 5,000 km; and has suffered a demonstrable decline in extent in Western Australia with the species not being recorded from former sites north of Dundas Nature Reserve and from near Eucla. It is not known whether targeted searches have been made in these two former parts of the species distribution in Western Australia in recent years. Based on IUCN criteria for listing plants, *Vittadinia blackii* can be considered as endangered in Western Australia and should be considered for listing under threatened species schedules for that state.

Victoria

There are six relatively recent confirmed records of the species in Victoria (Table 2) with all occurring in western Victoria; Wail State Forest (two records from 2000), Pine Plains (three records 1985, 1986 and 1993) and nearby Bronzewing Flora and Fauna Reserve (one 2007 record). One record from Pine Plains was recorded in a 1993 flora survey of the area (Sluiter *et al.* 1997) and was not supported by a herbarium specimen and so only 5 herbarium records are listed in Table 2. The Victorian Dept. of Sustainability and Environment (DSE) currently list *Vittadinia blackii* as vulnerable (DSE 2005) although that status will be elevated to endangered (David Cameron – DSE – personal communication) based on the fact that the species satisfies IUCN criteria A4, B2b, B2c and C2b. Specifically, the area of occupancy is less than 500 km, the number of subpopulations is five or less and there are 'extreme fluctuations in the numbers of mature individuals'. The species would also satisfy criterion C whereby there are likely to be less than 2,500 mature individuals in Victoria. Moreover, it is also likely that the species has experienced a loss of potential habitat in cleared Mallee dryland farming areas between the Big Desert and Little Desert (Criterion A – Reduction in Population Size).

New South Wales

Relatively recent records of *Vittadinia blackii* in New South Wales (Table 2) occur at Round Hill Nature Reserve in central New South Wales (one record from 1994), and in southwest New South Wales from 80 km

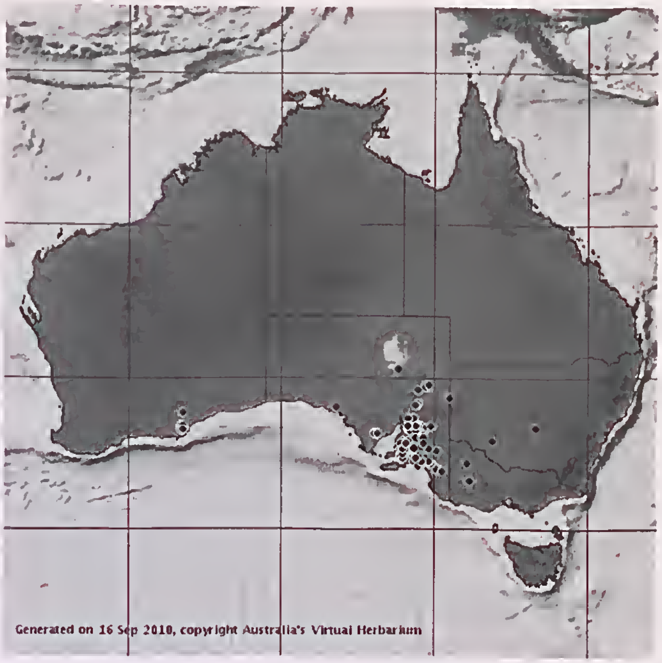
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Fig. 2. Distribution of *Vittadinia blackii* across southern Australia as shown on Australia's Virtual Herbarium website on the 16th September 2010.

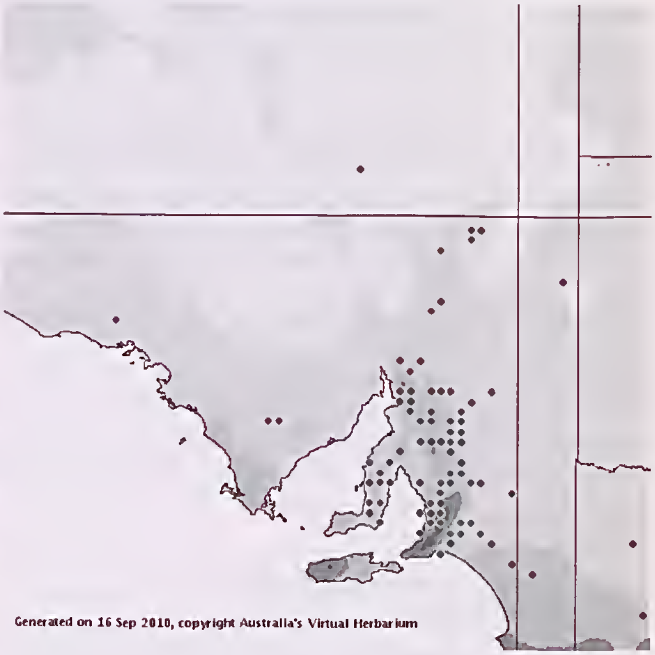
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Fig. 3. Distribution of *Vittadinia blackii* in South Australia across rainfall gradients from ~200 mm near Lake Eyre South and ~800 mm in the Adelaide Hills.

northwest of Balranald (one record from 1970) and a new 2010 record from 40 km west of Pooncarie. Although with widely separated occurrences, the distribution of *Vittadinia blackii* occurs over approximately 300 km in New South Wales.

There are also two pre 1900 records from western New South Wales (Table 2) but their precise locations are unknown. Cunningham *et al.* (1982) in their *Plants of western New South Wales* reported *Vittadinia blackii* as syn. *Vittadinia. tenuissima* "*as an uncommon species in the region, collected only from the Euston and Booligal districts in the south*".

Vittadinia blackii is currently not listed on schedules of the NSW *Threatened Species Conservation Act* 1995 and is consequently considered to be not threatened within New South Wales by the Dept. of Environment Climate Change and Water. Based on IUCN criterion B1a, B1b, B2a and B2b, that is 'extent of occurrence' and 'area of occupancy' respectively, *Vittadinia blackii* can be considered endangered in New South Wales because:

- it occurs over an area < 500 km
- it has fewer than five known subpopulations; and
- is inferred to have suffered from extreme fluctuations in the number of known individuals.

With respect to the above criteria, the site west of Pooncarie contains less than 20 plants whilst the site northwest of Balranald contained, apparently, a sufficient number of plants to be considered "fairly common" in 1970. However, there have been no records of the species from that area for 40 years despite extensive baseline flora surveys of nearby properties by the author in both 1999 and 2000. On this basis, *Vittadinia blackii* may also satisfy IUCN criterion C whereby there are less than 2,500 mature individuals, although this cannot be determined accurately at this stage. Clearly *Vittadinia blackii* is rare and threatened in New South Wales. It is strongly recommended that the species should be listed for protection as an endangered species under the *Threatened Species Conservation Act* 1995, especially given potential threats in the southwest part of the State from increased areas of sand mining and currently active clearing and cultivation licenses.

Conclusions

The small shrub *Vittadinia blackii* found across southern Australia is moderately common over a wide geographic spread of sites encompassing arid, semi-arid and temperate sub-humid parts of South Australia and is not threatened in that state. In adjoining states records indicate generally small ranges with a low number of known sites. Based on IUCN criteria for listing threatened plant species, which are currently in use across most of Australia, *Vittadinia blackii* should be considered endangered in Western Australia, Victoria and New South Wales; and hence qualifies for listing under each state's respective threatened species schedules. Victoria currently recognises *Vittadinia blackii* as threatened and has recently reviewed its conservation status and recommended that status be upgraded from vulnerable to endangered. New South Wales and Western Australia should include the species in their threatened species schedules as well.

Acknowledgements

The author wishes to thank David Cameron and Tony Auld for advice and discussions on IUCN threatened species criteria for *Vittadinia blackii* and Neville Walsh for information concerning the veracity and status of collections within Victoria. The National Herbarium of Victoria is thanked for supplying the data used from that institution under a data supply agreement titled "Royal Botanic Gardens Melbourne, MELISR database, 10th June 2010".

References

Baskin, J.M. & Baskin, C.C. (1989). Physiology of dormancy and germination in relationship to seed bank ecology. *In,* M.A. Leck, V.T. Parker and R.L. Simpson (Eds.) *Ecology of Soil Seed Banks*, Academic Press, San Diego, California, USA.

Burbidge, N.T. (1969). Notes on *Vittadinia triloba* sens. lat. (Compositae). *Proceedings of the Linnean Society of New South Wales* 93: 439–443.

Burbidge, N.T. (1982). A revision of *Vittadinia* A. Rich. (Compositae) together with reinstatement of *Eurybiopsis* DC. and description of a new genus, *Camptacra. Brunonia* 5(1): 1–72.

Cunningham, G.M., Mulham, W.E., Milthorpe, P.L & Leigh, J.H. (eds) (1982). *Plants of Western New South Wales.* (New South Wales Government Printing Office).

DSE (2005). *Advisory List of Rare or Threatened Plant Species in Victoria – 2005.* Victorian Department. of Sustainability and Environment, East Melbourne, Victoria.

Facelli, J., Chesson, P. & Barnes, N. (2005). Differences in seed biology of annual plants in arid lands: a key ingredient of the storage effect. *Ecology* 86(11): 2998–3006.

IUCN (2001). *IUCN Red List Categories and Criteria. Version 3.1.* (International Union for the Conservation of Nature Species Survival Commission, Gland, Switzerland and Cambridge, UK).

Jessop, J.T. & Toelken, H.R. (eds) (1986). *Flora of South Australia.* (South Australian Government Printing Division).

Sluiter, I.R.K., Minchin, P.R. & Jaensch, S.C (1997). The Buloke and Pine Woodlands of semi-arid and dry sub-humid Victoria and nearby areas. Unpublished report to the Australian Nature Conservation Agency and the Victorian Department of Natural Resources and Environment.

Trémont, R.M. (1995). The phenologies of six native herbs (*Aphanes australiana, Isoetopsis graminifolia, Triptilodiscus pygmaeus, Solenogyne dominii* and *Vittadinia muelleri*) occurring in grazed grassy communities on the Northern Tablelands of New South Wales. *Cunninghamia* 4(1): 21–34.

Willis, A.J. & Groves, R.H. (1991). Temperature and light effects on seven native forbs. *Australian Journal of Botany* 39: 219–228.

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The vegetation of the Coonavitra area, Paroo Darling National Park, western New South Wales

M. Westbrooke, S. Gowans and M. Gibson

Centre for Environmental Management, University of Ballarat, PO Box 663 Ballarat, Victoria, 3353, AUSTRALIA.

Abstract: The vegetation of Coonavitra area, Paroo Darling National Park (latitude 31°00'–32° 40'S and longitude 142°10'–144°25'E) in north western New South Wales was assessed using intensive quadrat sampling and mapped using extensive ground truthing and interpretation of aerial photograph and Landsat Thematic Mapper satellite images. In the survey 261 vascular plants species including 37 (14%) exotic species, from 50 families were recorded. Eighteen vegetation communities were identified and mapped, the most widespread being *Casuarina pauper/Alectryon oleifolius* low open woodland, *Acacia loderi* tall open shrubland, *Flindersia maculosa* low open woodland and *Acacia aneura* open-shrubland. Of particular significance are the extensive areas of *Acacia loderi* and *Acacia melvillei* tall open shrubland and one of the northernmost occurrences of *Eucalyptus socialis* tall open shrubland. Many of these communities have been impacted by a history of 150 years of pastoral use.

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Introduction

Paroo Darling National Park (lat 31° 00'–32 ° 40'S; long 142 ° 10'–144 ° 25'E) in north-western New South Wales, north-east of the town of Wilcannia (Fig. 1), covers an area of approximately 221,000 ha. The park, gazetted in October 2002, incorporates the previously gazetted Peery National Park with the addition of Mount Murchison, Wilga, Coonavitra and Tilpilly pastoral stations. As a result Paroo Darling National Park is made up of six separate non-contiguous areas (Fig. 1). The northernmost area is known as the Peery Lake area (and formerly Peery National Park) and is made up of the former pastoral stations of Peery, Mandalay and Arrow Bar. The Mount Murchison and Wilga areas are separated by the Darling River. The Coonavitra area, south-east of these areas, has a Northern block (north of the Barrier Highway) and a Southern block (south of the Barrier Highway). The southern block of Coonavitra is also referred to as the Emmdale block. The Tilpilly area between the Barrier Highway and the Wilcannia-Bourke Road is the eastern most extent of the park.

Major features of the park are Peery Lake, part of the Paroo Overflow, and the rugged sandstone hills to the west of the lake. Other features are the Darling River that flows between the Mount Murchison and Wilga areas, and the rugged Greenough Hill range of the Northern block of Coonavitra. The study area falls within the Murray Darling Depression Bioregion.

Detailed surveys and vegetation maps have been completed for the Peery Lake area (Westbrooke *et al.* 2002; Westbrooke *et al.* 2003) and the Tilpilly area (Hunter & Fallavollita 2003). In June and November 2005 an intensive vegetation survey of the Mount Murchison, Wilga and Coonavitra blocks, Paroo Darling National Park was conducted. Prior to this study no systematic survey of the vegetation of these

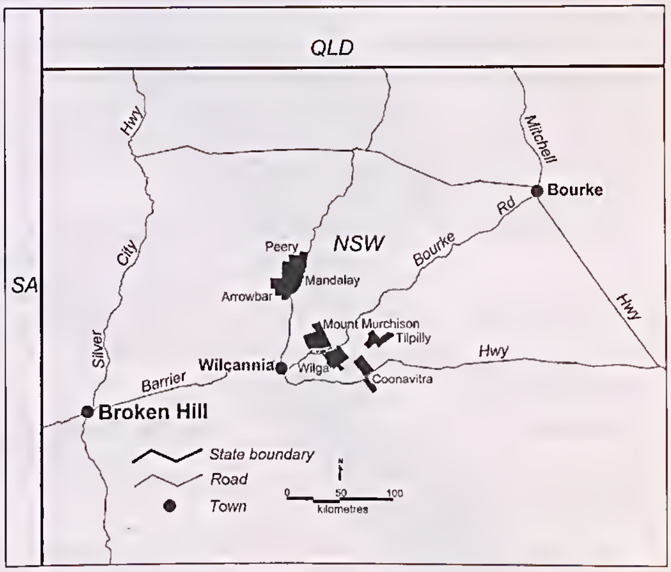

Fig. 1. Location of Paroo Darling National Park

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parts of the park had been done. Because of the contrasting landsystems represented, the results of the survey for the Mount Murchison and Wilga areas are presented separately from the Coonavitra area (Westbrooke *et al.* 2006). This paper details the findings of the vegetation survey for the Coonavitra area of Paroo Darling National Park.

History of the area

Prior to European settlement, nomadic Aboriginal tribes, who were able to travel away from permanent soaks, waterholes and native wells, inhabited the area after favourable rains. The Paakantji Aboriginal people travelled the length of the Darling River from Wileannia through Menindee, towards Wentworth. The Ngiyeempaa people occupied the land south-east of the Darling River. The large number of middens and stone relics encountered today provide evidence of the strong ties of both tribes to the river (H. Johnston, NSW Parks & Wildlife Service, Buronga, pers. comm.). The first Europeans to travel through the area were Charles Sturt and his party who followed the Darling River to Menindee and then travelled west to the Barrier Range and north into Queensland (Stanley 1991). Soon after, others followed the Darling River in search of pasture for sheep. Robert Gow explored the area in 1861 (Jervis 1948) but Vincent Dowling, who had established a cattle station close to the mouth of the Warrego River, had explored the Paroo River to the north-west in 1860 and applied for grazing rights (Heathcote 1965). The township of Wileannia was surveyed in 1865 and soon thrived (Hardy 1969). Previously there was just a woolshed and a few huts at Mount Murchison Station. Soon after, 38 runs were taken up as Momba (848,000 ha.) which incorporated the existing Mount Murchison lease (Pickard 1990). Smith, Elder and Waite held the Momba pastoral

Table 1. Characteristics and occurrence of Land systems across the Coonavitra area (Walker 1972; Hazelton 1977)

Relief & system	Area	Characteristics
Rolling downs and lowlands		
Lilyvale (Lv)	Emmdale block	Undulating rounded quartzite and sandstone ridges, partly covered by aeolian sand, narrow incised drainage lines. Relief to 15m. Shallow, stony, loamy soils on upper slopes. Shallow to deep sands and red earths on lower slopes.
Plains		
Coonavitra (Cv)	Northern block	Sandy accumulation on range footslopes, level Sandplain with wind-blown sand accumulation. Relief to 5m. Calcareous red earths with sandy surface.
Fulham (Fu)	Emmdale block	Plains with scattered dunes and small drainage sinks. Relief to 5m. Calcareous loamy or sandy slightly ferruginous red earths. Dunes of deep sands. Drainage sinks of calcareous red earths and some cracking clays.
Manara (Ma)	Emmdale block	Extensive plains with few dunes, low sandy accumulations and small drainage sinks. Relief to 5m. Calcareous red earths and solonised brown soils, with sands and sandy earths on dunes, and sandy earths or sandy texture-contrast soils on rises. Drainage sinks.
Nelia (Ne)	Northern block & Emmdale block	Extensive plains with few dunes, and small and large drainage sinks. Relief to 5m. Level solonised brown soils, becoming slightly undulating near larger sinks, and some red-brown texture-contrast soils. Dunes of calcareous sandy earths or sands. Sinks of heavy clay or solonised brown soils.
Dunefields		
Bell Vale (Bv)	Emmdale block	Dunefield with east-west orientated dunes, narrow to broad swales, and drainage sinks. Relief to 5m. Dunes of sands and sandy earths. Swales of calcareous red earths and reddish-brown clay soils. Drainage sinks of calcareous red earths and clay soils.
Blackfella (Bf)	Emmdale block	Sandplain with low east-west oriented dunes and few small drainage sinks. Relief to 3m. Sands and sandy earths. Few small open areas of calcareous red earths and clay soils.
Ranges		
Boorandarra (Bz)	Northern block	Strongly bevelled quartzite and sandstone ridges and footslopes. Relief to 200m. Shallow, stony, sandy soils, becoming deeper and better developed downslope. Narrow valleys of red earths, incised channels.
Hills and footslopes		
Mulga Downs (Mz)	Northern block	Low, partly bevelled quartzite and sandstone ridges and footslopes with narrow alluvial valleys. Relief to 50m. Shallow, stony, sandy soils, grading to deeper and better developed red earths downslope.
Playas and basins		
Karumpito (Ko)	Northern block & Emmdale block	Small lakes in red country with local catchments. Beds of cracking or non-cracking clays and solonised brown soils, with sandy surface deposits around shorelines. Lunettes of sandy solonised brown soils, often shallow overlying calcrete.

lease from early 1870 (Heathcote 1965). In 1889 it was reported that Momba was overrun by kangaroos (Heathcote 1965). About this time a party of shooters found opal in the sandstone hills and by the 1890s White Cliffs township was established (Hardy 1969). With the development of pastoral leases in the 1850s, Aboriginal people were moved from their traditional homes to government missions at Menindee, Ivanhoe and Lake Cargelligo.

The combination of drought and overstocking made the normal recurrence of drought a major disaster. Whereas the land returned rapidly from 'desert' to 'vital glory' after the 1865–70 drought, this was no longer the case by the end of the century and by 1901 there was a catastrophic decline in productivity in the West Darling area. Sheep numbers that had gone from less than two million prior to 1880 to a peak of nearly eight million by 1894, had declined to less than three million again by 1901. After 1902, Momba was successively subdivided until around 1950 when the residue was divided into ten leases which included Peery, Mandalay and Arrow Bar (Pickard 1990).

Peery Station, the first of several pastoral properties to be acquired in the area, was identified as an area of particular conservation value and acquired in 1999 to protect natural and cultural heritage. Peery National Park was proclaimed in March 2000 (NPWS 2000) and the acquisition of Arrow Bar and Mandalay leases in December 2000 gave protection to the entire Peery Lake basin.

Coonavitra Station was part of the resumed area of the original Cultowa run. Colin Wheeler acquired the Coonavitra lease in 1947 and held it till his death in 1989 when his family sold parts of the lease. In June 2000 the National Parks and Wildlife Service acquired the remainder, followed by the Mount Murchison lease on the northern side of the Darling River. The subsequent purchase of Wilga Station, bordering Mount Murchison on the southern bank of the Darling, provided a link between the northern and southern properties and led to the proclamation of Paroo Darling National Park, incorporating what had previously been Peery National Park in October 2002.

Climate

The climate for the area is arid with low and unreliable rainfall (Edwards 1979). Temperatures are high in summer and mild in winter with average daily maximum of 35°C in January and 17°C in July and average daily minimum of 21°C in January and 4°C in July. The mean annual rainfall is approximately 250 mm and annual potential evaporation is 2738 mm. There is a slight summer bias to rainfall and annual variation is high (Clewett *et al.* 1994).

Geology and geomorphology

Three physiographic regions (Abraham 1991) occur within the Park; the Paroo plains of the eastern sector are separated from the Stony Tablelands and Plains by the Mount Pleasant sandstone hills (Morton 1991). The 12 land systems present (Milthorpe 1991) are summarised in Table 1.

The Northern block of Coonavitra supports a large expanse of sand plains in the south and the quartzite and sandstone Greenough Hill range in the north-west. The Emmdale block (Southern block) of Coonavitra supports extensive plains along with dunefields around the boundary with quartzite ridges near the southern boundary. Five land systems for the Northern block and seven land systems for the Emmdale block by are described Walker (1972) and Hazelton (1977) (Table 1). The distribution of the land systems across the Coonavitra area is shown in Fig. 2.

Previous studies

The most complete study of the vegetation of far western New South Wales is that by Beadle (1945; 1948) who included the study area as *Casuarina pauper / Alectryon oleifolius* subsp. *canescens* association along with claypans and swamps associated with the Darling River. Milthorpe (1991) and Pickard and Norris (1994) broadly describe the vegetation of the north-west corner of New South Wales, including the Peery Lake area of Paroo Darling National Park. Parts of the area now included in the Park were included in

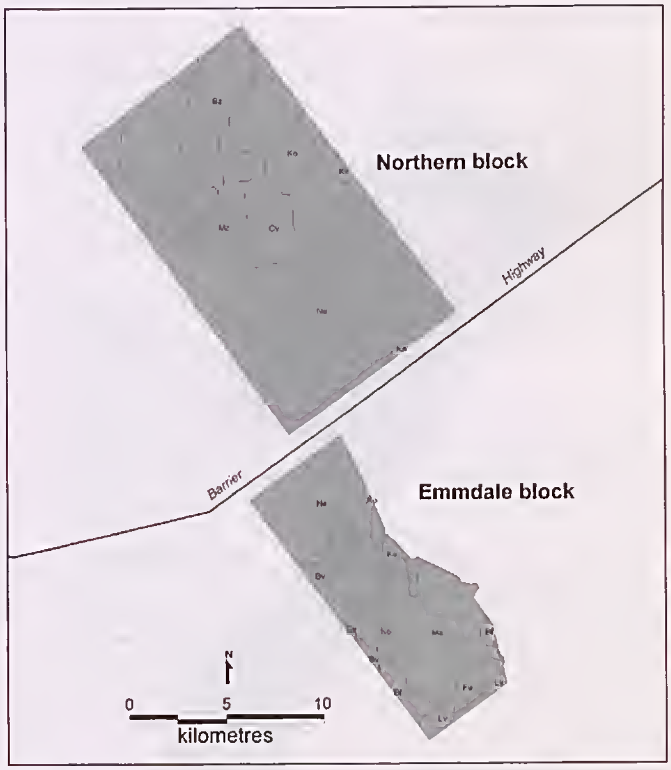

Fig. 2. Distribution of land systems within Coonavitra section, Paroo Darling National Park
(Key to codes used can be found in Table 1)

studies undertaken for the Wilderness Society (Lembit 1993; Knight 1994). A detailed survey and vegetation map have been completed for the Peery Lake area (Westbrooke et al. 2002; Westbrooke et al. 2003) and the Tilpilly area (Hunter & Fallavollita 2003). No systematic survey of the vegetation of Coonavitra had been undertaken prior to this study.

Methods

Study area

The Northern block of Coonavitra is approximately 95 km east of Wilcannia, north of the Barrier Highway and incorporates approximately 19,320 ha of the former Coonavitra Pastoral Station (the Coonavitra Homestead is 2 km north of the Barrier Highway; there are old yards and woolsheds just north of the Homestead). The study area takes in the Greenough Hill range. Following significant rain, a number of swamps and waterholes (Gulguy and Markaira Waterholes) hold water. Four named tanks (Bokara, Thoongama, Woolshed and Old Coonavitra), and two named bores (Bokara and Coolabah) (Fig. 3) were constructed for pastoral use prior to the park gazettal.

The Southern (Emmdale) block of Coonavitra is south of the Barrier Highway and incorporates 8,437 ha of the former Coonavitra Station (a number of old yards are scattered across the park). Several swamps hold water following significant rain and there are four named tanks (Hamton, Kurumpto and Eram), and one named bore (Bruton) constructed prior to park gazettal (Fig. 3).

Transect survey

A preliminary survey of vegetation communities within Coonavitra was undertaken in June 2005, following three years of drought. A transect-based sampling strategy was employed. Driven transects followed existing vehicle access tracks and fence lines, walked transects were across country. All transects were tracked using a Global Positioning System (GPS) receiver in the Australian Map Grid projection (Zone 54 and 55) and the 1984 World Geodetic System datum. The survey included approximately 205 km of walked and driven transects (Fig. 3). Vegetation communities along these transects were recorded and dominant perennial species listed for each community. A preliminary vegetation map at a scale of 1: 50,000 was prepared. Details of how information was collected along these transect and used to define vegetation communities are outlined below.

Table 2. Modified Braun-Blanquet scale (Kershaw & Looney 1985

Scale	Definition
+	Few individuals, less than 1% cover
1	Any number of individuals, less than 5% cover
2	Any number of individuals, 6–25% cover
3	Any number of individuals, 26–50% cover
4	Any number of individuals, 51–75% cover
5	Any number of individuals, 76–100% cover

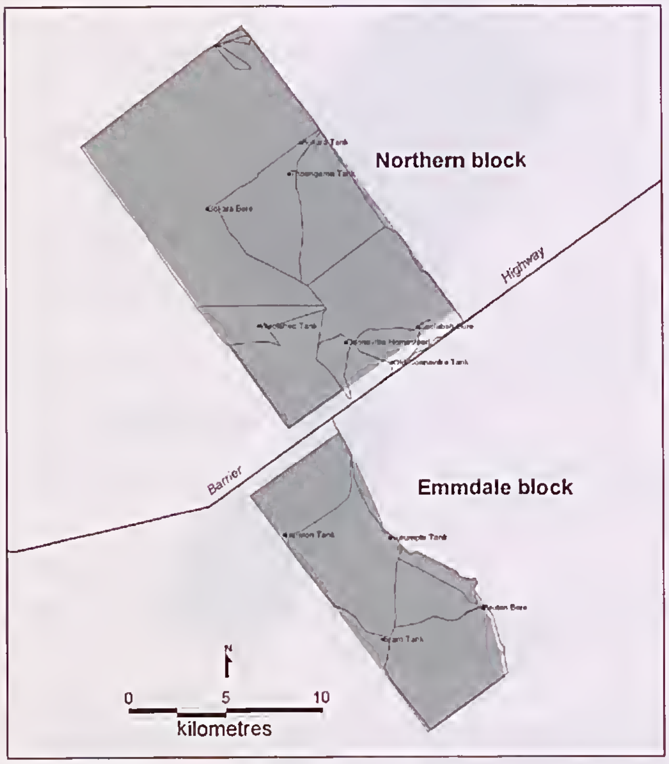

Fig. 3. Survey transects for the Coonavitra area

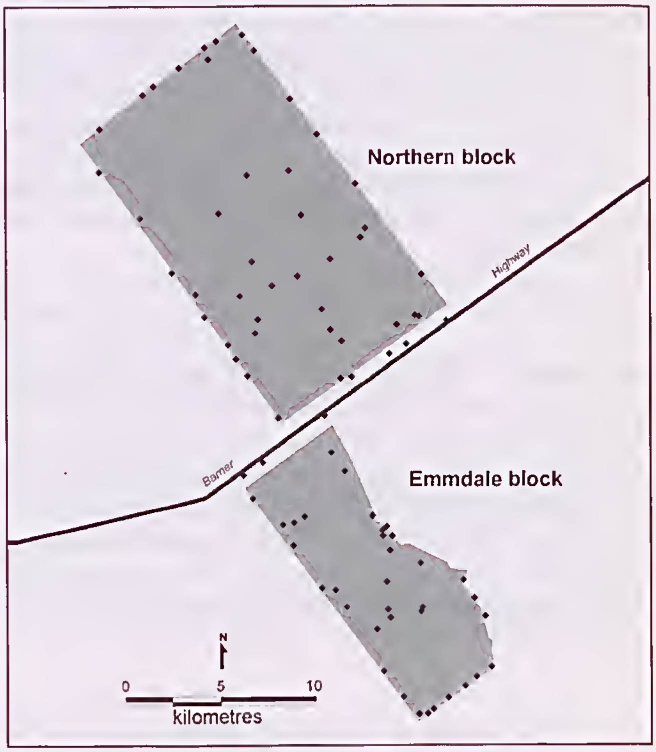

Fig. 4. Quadrat locations for the Coonavitra area

Quadrat survey

In November 2005 following good winter rainfall, a detailed floristic survey was undertaken. A quadrat-based sampling strategy was employed to survey the floristic composition of the vegetation communities. All quadrats were 900 m² (30 m x 30 m) in size. The sampling strategy was based on the preliminary vegetation map prepared following the June survey. Communities were generally sampled in proportion to the area they covered but to enable characterisation of communities, those of limited distribution may have been relatively over-sampled. All quadrat locations were recorded using a Global Positioning System (GPS) receiver in the Australian Map Grid projection (Zone 54 and 55) and the 1984 World Geodetic System datum. All vascular plant species occurring in each quadrat were recorded, identified to species level where possible and their conservation status determined. All flora were given a cover / abundance value, modified from Braun-Blanquet scale (as in Kershaw & Looney 1985) (Table 2).

The field survey was undertaken during early spring following good winter rains to take advantage of the opportunities for plant identification, particularly grasses, herbs and forbs. Some later spring-flowering grasses, herbs and forbs may have been dormant at this time and not observed. Similarly,

Table 3 Vegetation communities of Coonavitra with their area and relationship to soil and landform

Note: The total mapped area is 20,174 ha for the Northern block and 8,970 ha for the Emmdale block including the park and the road reserve between the blocks. Point locations of communities (i.e. Anthropogenic herbland) have been treated as occupying approximately 1 ha. Equivalent Benson (2006) vegetation community I.D numbers are shown in bracket

Vegetation community	**Area (ha) approx**		**Soil and landform**
	North	**Emmdale**	
Woodlands			
Callitris glaucophylla open woodland (246)	-	12	Sandy rises within the Bell Vale, Manara, Blackfella and Nelia landsystems of the Emmdale block.
Casuarina pauper / Alectryon oleifolius low open woodland (58)	9,124	4,943	Calcareous sandplains of the Nelia landsystem of both blocks and sandplains of the Bell Vale, Manara and Fulham landsystems of the Emmdale block.
Eucalyptus coolabah / Eucalyptus largiflorens open woodland (38)	56	-	Fringing lakebeds of the Nelia landsystem of the Northern block.
Eucalyptus intertexta open woodland (108)	4	136	Undulating sandstone ridges of the Nelia landsystem of the Northern block and the Manara and Lilyvale landsystems of the Emmdale block.
Eucalyptus populnea open woodland (207)	546	648	Sinks within alluvial plains of the Karumpito and Nelia landsystems of both blocks and the Manara landsystem of the Emmdale block.
Flindersia maculosa low open woodland (144)	4,175	55	Aeolian sands and calcareous plains of the Coonavitra and Nelia landsystems of the Northern block and the Manara landsystem of the Emmdale block.
Tall shrublands			
Acacia aneura tall open shrubland (hills) (120)	2,348	380	Quartzite and sandstone hills of the Mulga Downs and Boorandarra landsystems of the Northern block and the Lilyvale, Manara and Nelia landsystems of the Emmdale block.
Acacia loderi tall open shrubland (128)	3,691	1,080	Calcareous plains of the Nelia landsystem.
Acacia melvillei tall open shrubland (23)	12	553	Calcareous plains of the Nelia landsystem.
Eucalyptus socialis tall open shrubland (173/193)	118	780	Aeolian dunes of the Nelia landsystem of both blocks and the Blackfella and Manara landsystems of the Emmdale block.
Hakea leucoptera tall open shrubland (199)	-	1	Plains of the Nelia landsystem.
Hakea tephrosperma tall open shrubland (199)	-	1	Plains of the Nelia landsystem.
Low shrublands			
Acacia victoriae open shrubland (139)	37	-	Undulating plains and dunes of the Nelia landsystem.
Eremophila / Dodonaea open shrubland (143)	-	340	Plains of the Nelia landsystem.
Grasslands			
Eragrostis australasica hummock grassland (24)	1	60	Lakes and depressions of the Karumpito landsystem.
Herblands			
Anthropogenic herbland	7	5	Areas subject to significant disturbance, including earth tanks and yards.
Lakebed herbland (166)	66	1	Lakes of the Karumpito landsystem of both blocks and the Blackfella landsystem of the Emmdale block.

earlier spring-flowering plants may have completed their growth cycles and may not have been observed. Where dead material (e.g. leaves, stems, seeds) was available such species were recorded to family, genus or species level where possible.

An estimate of the typical height and a visual estimate of the projected foliage cover of both native and introduced species in the tree layer, tall shrub layer (approximately > 1 m high), small shrub layer (approximately < 1 m high) and ground layer were recorded for each quadrat. Visual estimates of the total percentage cover of bare ground, cryptogams, litter, logs and rocks were recorded for each quadrat. All quadrats were photographed to provide a record of the appearance of the site but were not intended to provide permanent monitoring points. For the Coonavitra area 85 quadrats were sampled, 46 for the Northern block and 39 for the Emmdale block (Fig. 4).

The 1: 50,000 vegetation map produced following the June field survey was verified by ground checking the mapped boundaries of the vegetation communities via driven transects.

The map (Appendix 2) is also available on the Cunninghamia website.

Data analysis

Information from the transects was used in conjunction with colour aerial photographs (NSW Dept of Lands) and Landsat Thematic Mapper satellite imagery (Scene 95–83) to produce a vegetation map at 1: 50,000 scale. Vegetation mapping was undertaken using a combination of ArcGIS 9.0 and MapInfo Professional Version 7.5 Geographic Information Systems. The mapped vegetation communities were defined by floristic and structural characteristics (Specht 1970) coupled with expert judgment and analysis. The communities were then compared to those communities outlined in Benson (2006) to determine the equivalent vegetation community name and their conservation status.

Data from quadrats were entered into a Microsoft® Access 2002 database and analysed using PATN (Belbin 1993) to determine the communities present. Further restricted and/or interesting communities recorded during the field survey but not evident from the numeric classification were added to the final classification. Most communities identified from the vegetation classification were mapped at the 1:50,000 scale. Additional vegetation types of restricted occurrence or not evident from the classification were located as points on the map. A species list was compiled for the study area incorporating all vascular plant species recorded from quadrats and additional species recorded opportunistically. The flora list also identifies which vegetation community each of the species was recorded in. For each vegetation community, mean species richness, total species richness and mean numbers of introduced species per quadrat were calculated.

Results

Vegetation

The southern area of the Northern block of Coonavitra consists predominantly of *Casuarina pauper / Alectryon oleifolius* low open woodland with patches of *Eucalyptus populnea* and *Eucalyptus largiflorens* open woodland in low-lying areas. To the north is extensive *Flindersia maculosa* low open woodland on the sandplains surrounding the Greenough Hill range. The range supports *Acacia aneura* tall open shrubland. Extending along the north-western boundary of the block is a large expanse of *Acacia loderi* tall open shrubland. In the south-eastern corner of the block are a few patches of *Eucalyptus socialis* tall open shrubland.

The Emmdale block consists mostly of *Casuarina pauper / Alectryon oleifolius* low open woodland on the sandplain. The north of the block consists of *Acacia loderi* tall open shrubland and *Acacia melvillei* tall open shrubland with patches of *Eucalyptus populnea* open woodland in low-lying areas. Drainage lines support *Eragrostis australasicus* tussock grassland and fringing *Eucalyptus populnea* open woodland. South of this are areas of *Eucalyptus socialis* tall shrubland with *Eucalyptus intertexta* open woodland and *Acacia aneura* tall open shrubland on the rocky hills.

Eighteen communities were recognised and described for the Coonavitra area, 13 for the Northern block and 15 for the Emmdale block (Table 3). While several of these are of limited distribution they add significantly to the conservation values of the Park. Map 1 shows the distribution of each of the vegetation communities. The floristic composition of vegetation communities are outlined later in this section. A total list of flora species recorded for each vegetation community is provided in appendix 1.

Woodlands

Callitris glaucophylla open woodland

Small areas of *Callitris glaucophylla* open woodland (Fig. 5) occur on sandy rises in the south of the Emmdale block. Associated understorey shrubs include *Dodonaea viscosa* subsp. *angustissima*, *Eremophila sturtii*, *Hakea tephrosperma*, *Enchylaena tomentosa*, *Sclerolaena obliquicuspis*, *Salsola kali* var. *kali*, *Chenopodium desertorum* and *Atriplex stipitata*. Ground layer species include *Rhodanthe corymbiflora*, *Austrostipa scabra*, *Gnephosis foliata* and *Harmsiodoxa brevipes* var. *brevipes*.

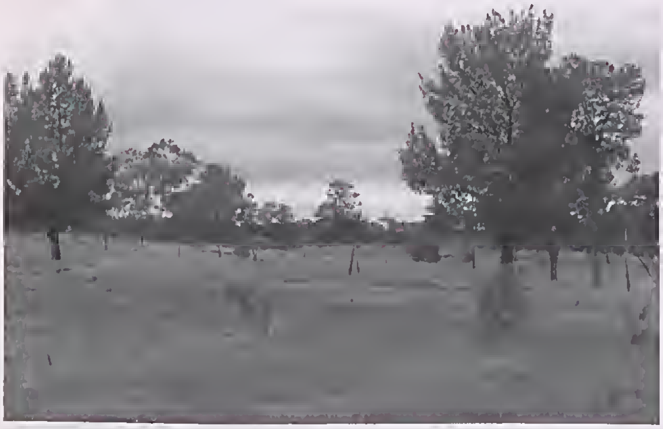

Fig. 5. *Callitris glaucophylla* open woodland

Casuarina pauper / Alectryon oleifolius low open woodland

Casuarina pauper / Alectryon oleifolius low open woodland (Fig. 6) growing to 10–12 metres tall is widespread on undulating sandplains including a large area in the south of the Northern block. Most commonly associated understorey shrubs are *Dissocarpus paradoxus*, *Sclerolaena obliquicuspis*, *Sclerolaena diacantha*, *Eremophila sturtii*, *Enchylaena tomentosa*, *Chenopodium desertorum*, *Chenopodium curvispicatum* and *Atriplex stipitata*. Commonly associated ground layer species include *Austrostipa scabra*, *Rhodanthe corymbiflora* and *Pycnosorus pleiocephala*.

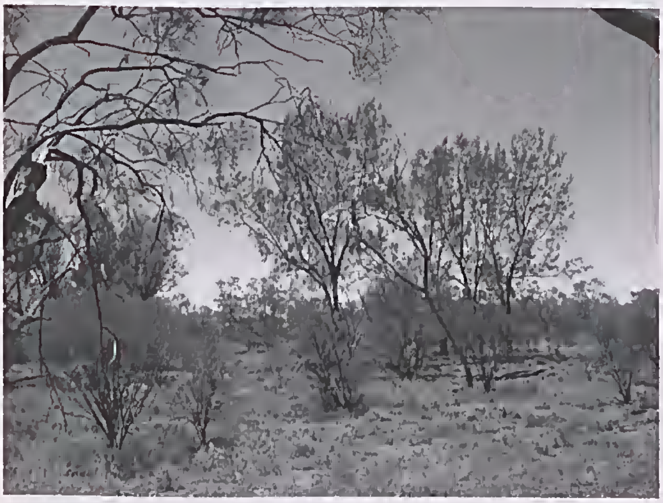

Fig. 6. *Casuarina pauper / Alectryon oleifolius* low open woodland

Eucalyptus coolabah / Eucalyptus largiflorens open woodland

Small areas of *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland (Fig. 7) (10 m tall) occur on heavy soils surrounding lakes in the south of the Northern block. Understorey shrubs frequently associated include *Dissocarpus paradoxus* and *Enchylaena tomentosa*. Associated ground layer species include *Pycnosorus pleiocephala*, *Rhodanthe floribunda* and *Plantago drummondii*.

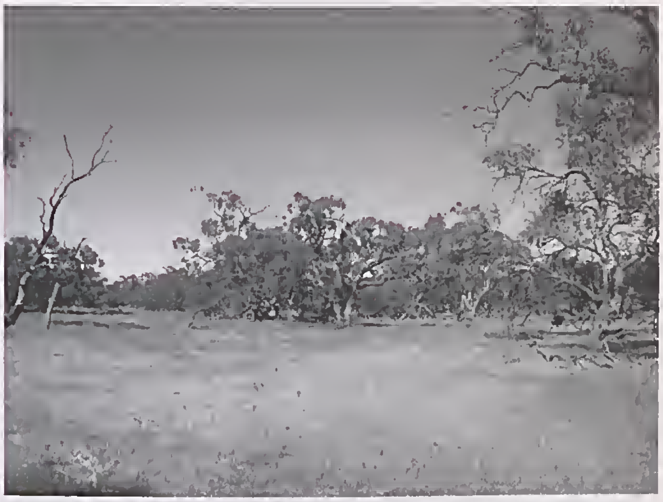

Fig 7. *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland

Eucalyptus intertexta open woodland

Eucalyptus intertexta open woodland (Fig. 8) (10 m tall) occurs on the sandy lower slopes of the sandstone hills located in the south of both blocks of the Coonavitra area. *Alectryon oleifolius* subsp. *canescens* is commonly associated. The shrubs *Sclerolaena diacantha*, *Sclerolaena convexula*, *Eremophila sturtii*, *Eremophila longifolia*, *Dodonaea viscosa* subsp. *angustifolia* and *Chenopodium desertorum* are frequently found within this community. Ground layer species frequently associated include *Rhodanthe corymbiflora*, *Waitzia acuminata* and *Austrostipa scabra*.

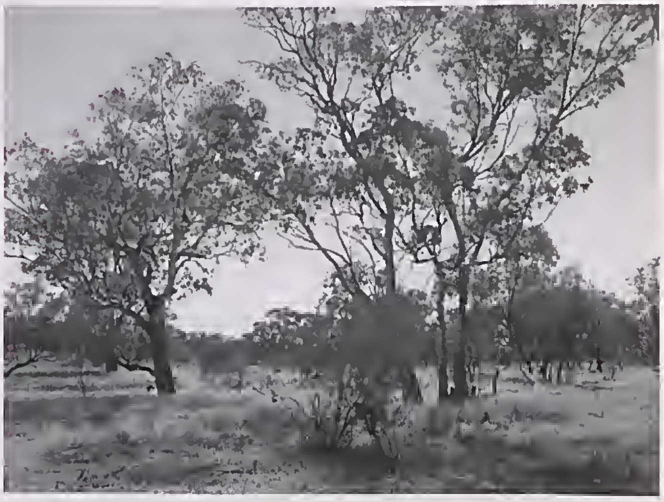

Fig. 8. *Eucalyptus intertexta* open woodland

Eucalyptus populnea open woodland

This open woodland (10 m tall) dominated by *Eucalyptus populnea* subsp. *bimbil* (Fig. 9) is associated with drainage lines and depressions. Understorey shrub species frequently associated include *Dissocarpus paradoxus*, *Eremophila sturtii*, *Atriplex stipitata*, *Enchylaena tomentosa*, *Dodonaea viscosa* subsp. *angustifolia* and *Sclerolaena obliquicuspis*. Associated ground layer species include *Austrostipa scabra*, *Pycnosorus pleiocephala*, *Einadia nutans*, *Rhodanthe floribunda* and *Rhodanthe corymbiflora*.

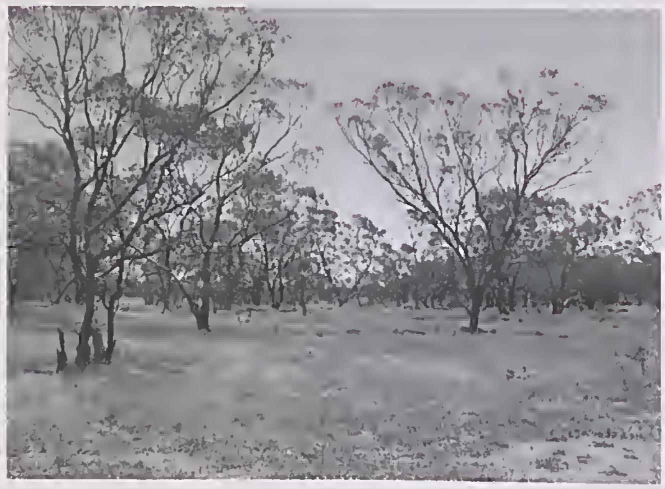

Fig. 9. *Eucalyptus populnea* open woodland

Flindersia maculosa low open woodland

Low open woodland dominated by *Flindersia maculosa* (Fig. 10) occurs on low hills and sandplains. *Alectryon oleifolius* subsp. *canescens* and *Apophyllum anomalum* are frequently associated. Associated shrubs include *Dissocarpus paradoxus*, *Sclerolaena obliquicuspis*, *Atriplex stipitata*, *Enchylaena tomentosa*, *Sclerolaena diacantha*, *Eremophila sturtii*, *Maireana pyramidata* and *Salsola kali* var. *kali*. Ground layer species include *Austrostipa scabra*, *Rhodanthe corymbiflora*, *Lepidium oxytrichum* and *Stenopetalum lineare*.

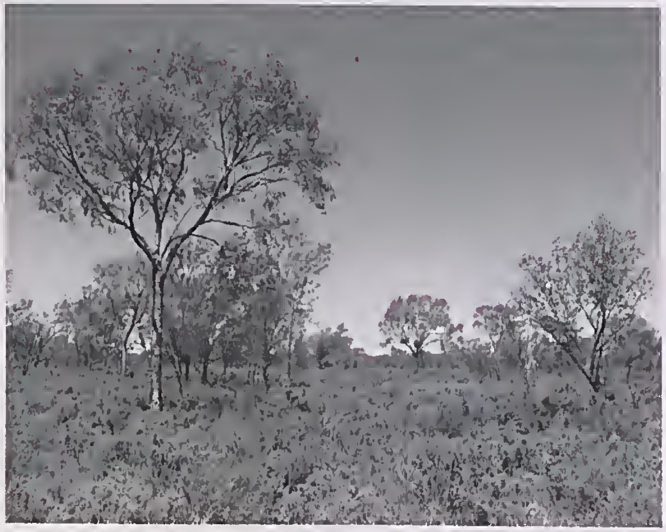

Fig. 10. *Flindersia maculosa* low open woodland

Tall shrublands

Acacia aneura tall open shrubland (hills)

Tall open shrubland dominated by *Acacia aneura* (Fig. 11) occurs on the rocky hills of the Greenough Hill range in the Northern block and the central and southern section of the Emmdale Block. Associated shrubs include *Sclerolaena convexula*, *Enchylaena tomentosa*, *Eremophila longifolia* and *Atriplex stipitata*. Ground layer species include *Rhodanthe corymbiflora*, *Austrostipa scabra*, *Ptilotus polystachyus* var. *polystachyus*, *Ptilotus atriplicifolius* var. *atriplicifolius*, *Lepidium oxytrichum*, *Daucus glochidiatus*, *Thyridolepis mitchelliana*, *Solanum ferocissimum*, *Stenopetalum lineare* and *Goodenia gracilis*.

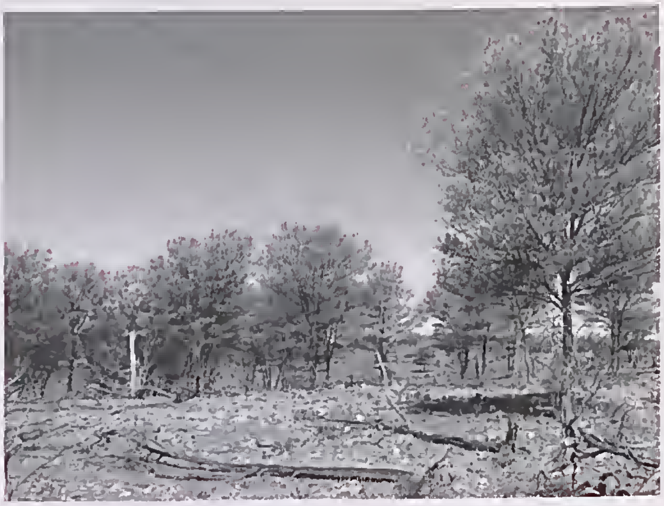

Fig. 11. *Acacia aneura* tall open shrubland (hills)

Acacia loderi tall open shrubland

Tall open shrubland dominated by *Acacia loderi* (Fig. 12) occurs over large areas of Coonavitra. Common associates are *Casuarina pauper* and *Alectryon oleifolius* subsp. *canescens*. Associated shrubs include *Dissocarpus paradoxus*, *Atriplex stipitata*, *Enchylaena tomentosa*, *Eremophila sturtii*, *Eremophila longifolia* and *Sclerolaena obliquicuspis*. Ground layer species include *Rhodanthe corymbiflora*, *Austrostipa scabra*, *Pycnosorus pleiocephala*, *Gnephosis foliata* and *Einadia nutans*.

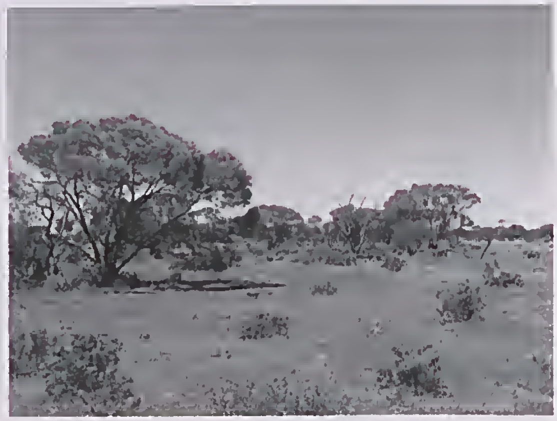

Fig. 12. *Acacia loderi* tall open shrubland

Acacia melvillei tall open shrubland

Tall open shrubland dominated by *Acacia melvillei* (Fig. 13) occurs in the north of the Emmdale block of Coonavitra. Common associates are *Acacia loderi*, *Casuarina pauper* and *Alectryon oleifolius* subsp. *canescens*. Most commonly associated understorey shrubs are *Dodonaea viscosa* subsp. *angustifolia*, *Eremophila sturtii*, *Sclerolaena obliquicuspis* and *Dissocarpus paradoxus*. Ground layer species include *Rhodanthe corymbiflora*, *Pycnosorus pleiocephala*, *Brachyscome lineariloba* and *Austrostipa nodosa*.

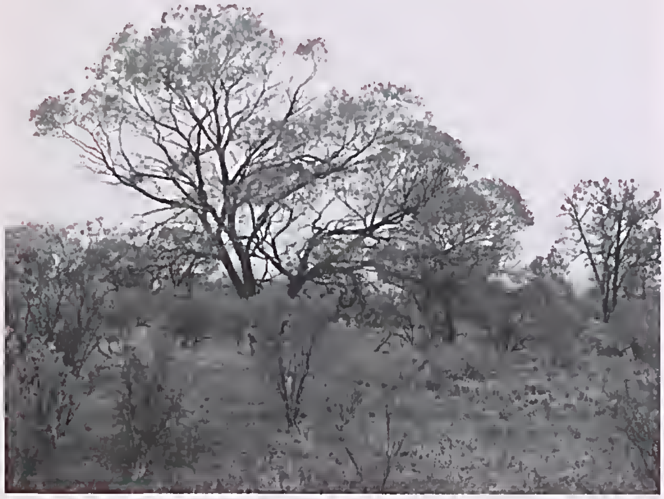

Fig. 13. *Acacia melvillei* tall open shrubland

Eucalyptus socialis tall open shrubland (shrub understorey)

Tall open shrubland dominated by *Eucalyptus socialis* (Fig. 14) occurs on low aeolian dunes in the south of the Emmdale block of Coonavitra. A small area of this community also occurs east of Coonavitra Homestead adjacent to Coolabah Bore. Understorey shrubs include *Dissocarpus paradoxus*, *Chenopodium desertorum*, *Atriplex stipitata*, *Eremophila sturtii*, *Sclerolaena diacantha*, *Sclerolaena parviflora*, *Senna form taxon 'petiolaris'*, *Maireana pentatropis*, *Pittosporum phylliraeoides*, *Zygophyllum eremaeum* and *Dodonaea viscosa* subsp. *angustifolia*. Ground layer species include *Austrostipa scabra*, *Ptilotus atriplicifolius* var. *atriplicifolius*, *Ptilotus polystachyus* var. *polystachyus* and *Rhodanthe corymbiflora*.

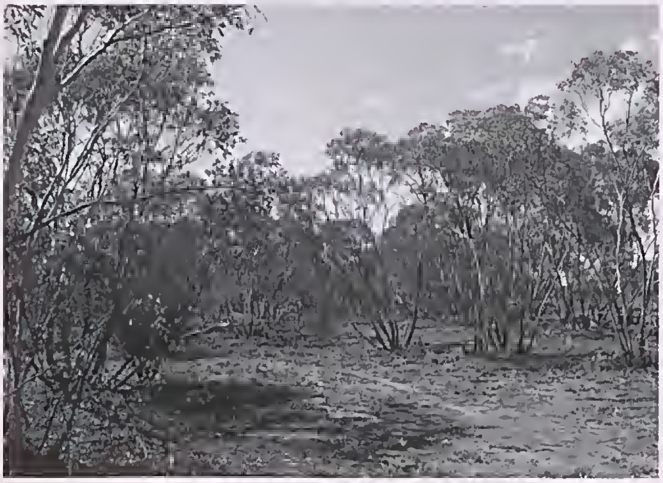

Fig. 14. *Eucalyptus socialis* tall open shrubland (shrub understorey)

Eucalyptus socialis tall open shrubland (Triodia understorey)

On deeper sands of the aeolian dunes tall open shrubland dominated by *Eucalyptus socialis* (Fig. 15) occurs with an understorey dominated by *Triodia scariosa*. Associated understorey shrubs include *Calotis plumulifera*, *Chenopodium desertorum*, *Dodonaea viscosa* subsp. *angustifolia*, *Halgania cyanea*, *Myoporum platycarpum*, *Sclerolaena diacantha*, *S. parviflora*, *Senna form taxon 'petiolaris'* and *Zygophyllum eremaeum*. Ground layer species include *Austrostipa scabra*, *Corynotheca lateriflora*, *Ptilotus exaltatus* var. *exaltatus*, *Ptilotus polystachyus* var. *polystachyus*, *Rhodanthe corymbiflora* and *Waitzia acuminata*.

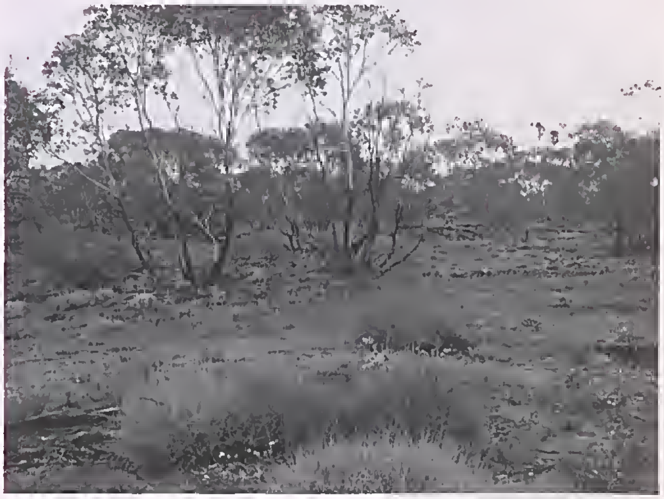

Fig. 15. *Eucalyptus socialis* tall open shrubland (*Triodia* understorey)

Hakea leucoptera tall open shrubland

Small patches of tall open shrubland dominated by *Hakea leucoptera* (Fig. 16) occur on sandplains. Associated shrub species include *Sclerolaena convexula*, *S. obliquicuspis*, *Dodonaea viscosa* subsp. *angustifolia*, *Calotis hispidula*, *Dissocarpus paradoxus* and *Enchylaena tomentosa*. Ground layer species include *Austrostipa nitida*, *Rhodanthe corymbiflora*, *Brachyscome lineariloba*, *Bracteantha bracteata*, *Pycnosorus pleiocephala* and *Stenopetalum lineare*.

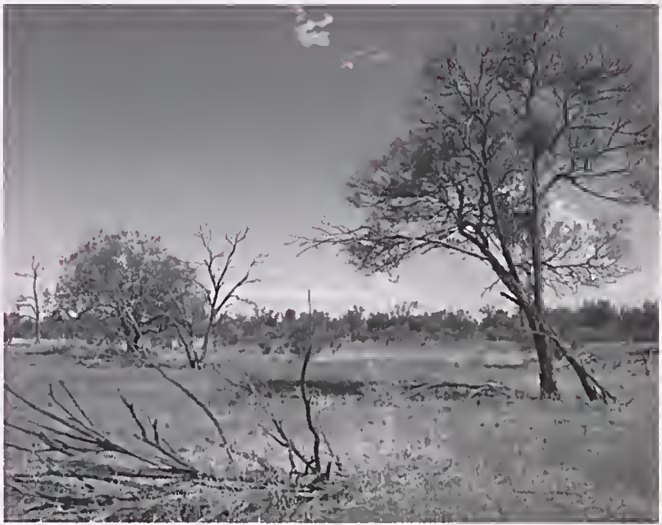

Fig. 16. *Hakea leucoptera* tall open shrubland

Hakea tephrosperma tall open shrubland

Small patches of tall open shrubland dominated by *Hakea tephrosperma* (Fig. 17) occur on sandplains. Shrub associates include *Dodonaea viscosa* subsp. *angustissima, Sclerolaena obliquicuspis, S. diacantha, Dissocarpus paradoxus* and *Chenopodium desertorum.* Ground layer species include *Pimelea trichostachya, Rhodanthe corymbiflora, Ptilotus polystachyus* var. *polystachyus* and *Austrostipa scabra.*

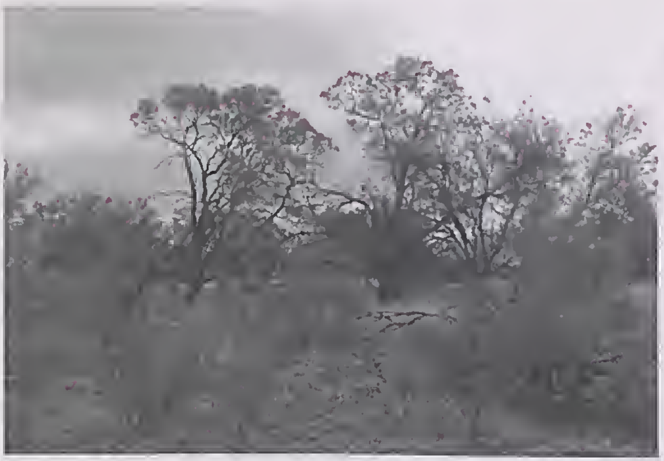

Fig. 17. *Hakea tephrosperma* tall open shrubland

Low shrublands

Acacia victoriae open shrubland

Acacia victoriae open shrubland (Fig. 18) occurs on sandy rises. Associated shrub species include *Maireana brevifolia, Enchylaena tomentosa* and *Dissocarpus paradoxus.* Ground layer species include *Rhodanthe corymbiflora, Austrostipa scabra* and *Pycnosorus pleiocephalus.*

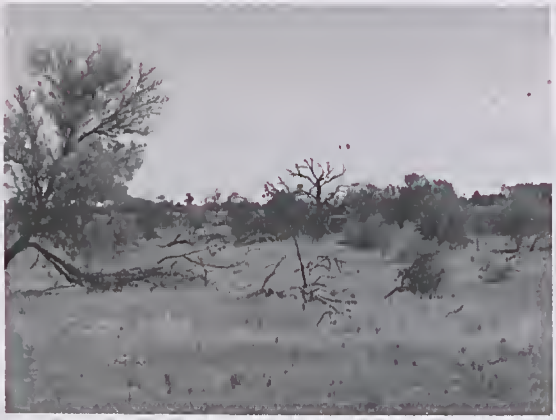

Fig. 18. *Acacia victoriae* open shrubland

Eremophila / Dodonaea open shrubland

On sandy rises are areas of mixed species shrubland in which *Dodonaea viscosa* subsp. *angustissima* and *Eremophila sturtii* are prominent (Fig. 19). This community is commonly associated with *Casuarina pauper / Alectryon oleifolius* low open woodland. Other associated shrubs include *Dissocarpus paradoxus, Einadia nutans, Chenopodium desertorum, Sclerolaena obliquicuspis, Sclerolaena muricata, Sclerolaena diacantha, Atriplex stipitata, Enchylaena tomentosa* and *Calotis hispidula.* Common ground layer associates include *Austrostipa trichophylla, Austrostipa scabra, Ptilotus atriplicifolius* var. *atriplicifolius, Ptilotus polystachyus* var. *polystachyus, Brachyscome lineariloba, Rhodanthe floribunda, Plantago turrifera, Harmsiodoxa brevipes* var. *brevipes* and *Stenopetalum lineare.*

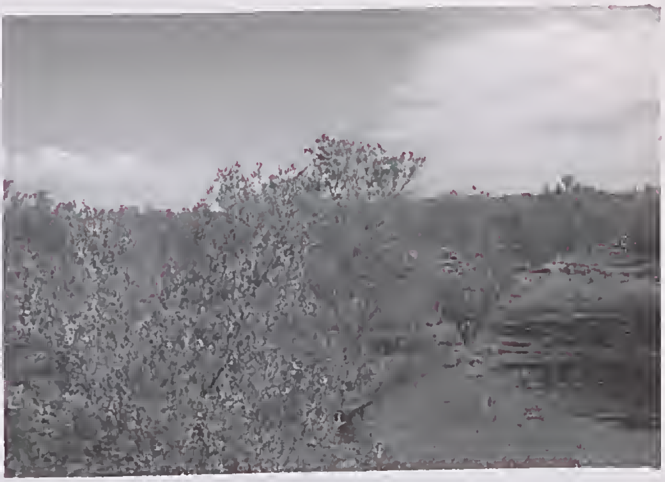

Fig. 19. *Eremophila / Dodonaea* open shrubland

Grasslands

Eragrostis australasica grassland

Areas of *Eragrostis australasica* grassland (Fig. 20) occur in shallow lakes and in relic lakes within sandplains. *Muehlenbeckia florulenta* may be associated and other associated low shrubs and herbs include *Pycnosorus pleiocephala, Lachnagrostis filiformis, Malva australiana, Rhadanthe corymbiflora, Sclerolaena tricuspis, Sclerolaena muricata, Plantago drummondii, Lepidium pseudohyssopifolium, Atriplex lindleyi* and *Myosurus minimus* var. *australis.*

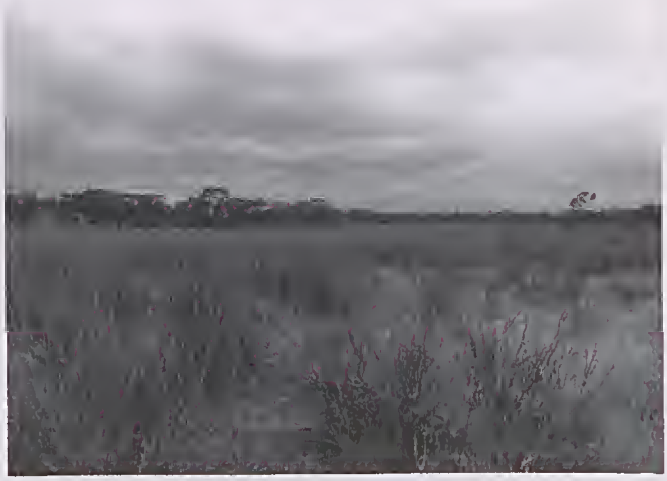

Fig. 20. *Eragrostis australasica* grassland

Herblands

Anthropogenic herbland

Sites which had been subject to significant disturbance through the pastoral history of the properties, including homestead sites, earth tanks (Fig. 21) and yards had a predictably, high proportion of weed species.

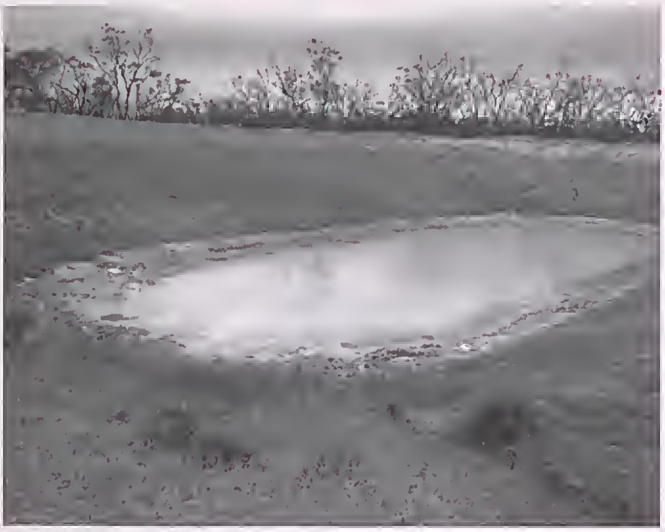

Fig. 21. Anthropogenic herbland

Lakebed herbland

As the lakes dry out after flooding an annual herbland develops (Fig. 22). This is dominated by annuals including *Scleroleana* species. It is likely that the species composition of these areas is variable and dependant on seasonality of rainfall events, with grasses becoming more prominent following good summer rainfall. These herblands warrant a more detailed study through several seasons.

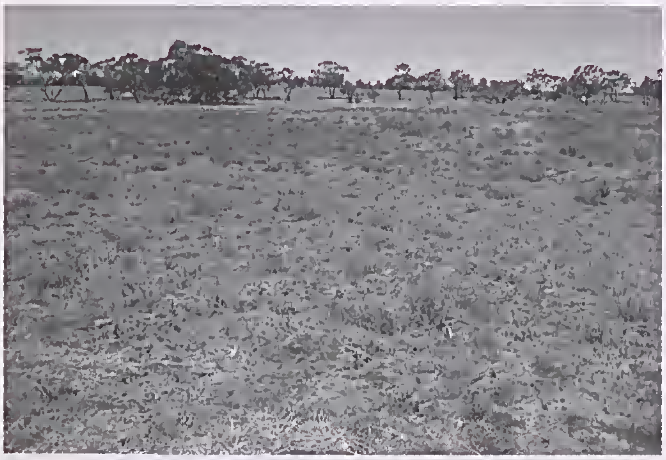

Fig. 22. Lakebed herbland

Plant species

A total of 261 vascular plant species from 50 families were recorded during this study of the Coonavitra area (appendix 1). Of the plant species recorded from the Park, 37 (14%) are introduced. The sampling effort in each vegetation community, mean and total native and introduced species richness is shown in Table 4.

Discussion

Mapping communities

There are a number of inherent problems in mapping vegetation: vegetation mapping assumes discontinuities between communities which may not exist; the constraints of cartography determine the minimum area that can clearly be distinguished; it is generally not feasible to groundtruth the whole of an area, thus parts of the map assume a consistent relationship between the vegetation and other features such as soil type and topography.

Beadle's (1948) map of western NSW (at approximately 1:1 000 000 scale) includes two units for the Coonavitra area. James's (1960) map of the Paroo-Upper Darling shows three vegetation units and Milthorpe (1991) 1:500 000 map of north western NSW shows five units. Pickard and Norris's (1994) 1:1 000 000 map of north-western NSW shows nine. In our 1:50 000 scale map, 14 units are mapped and a further three indicated by point location. It was difficult to separate the two *Eucalyptus socialis* tall open shrubland communities (i.e. shrub understorey and *Triodia* understorey) and areas supporting *Eucalyptus socialis* tall open woodland are mapped as one unit. The map suffers from the limitations noted above. The smallest area that could be mapped was 100 m wide. Some areas remote from tracks may include small patches of a different vegetation unit from that mapped.

During the survey over 200 km of driven and walked transects were traversed, and given the association of many vegetation communities with landscape features, boundaries could be drawn with some confidence. Current mapping technology enables changes to be readily incorporated, and it is hoped that the map will be refined following further botanical survey.

Distribution of communities

The distribution and species composition of vegetation communities within Paroo Darling National Park is largely determined by variation in topography, landform position and soil type. Eucalypt species open woodlands are associated with texture contrast soils of the major creeklines. Shrubland dominated by *Acacia aneura* occurs on the lithosols of the quartzite and sandstone hills with *Eucalyptus intertexta* woodland on the red earths that occur on the footslopes. Woodlands variously dominated by *Casuarina pauper*, *Acacia aneura* and *Flindersia maculosa* occur on desert loams. Other factors, notably past grazing history, have also played a role in determining the present distribution and floristic composition of the communities present.

Vegetation condition

Whilst this was not intended to be a detailed assessment of vegetation condition, regeneration of overstorey and perennial understorey species was noted. Species richness

Table 4. Sampling intensity, species richness and weediness of vegetation communities of the Coonavitra area

Vegetation community	No. of quads.	Native species richness		Introduced species richness	
		Mean	Total	Mean	Total
Woodlands					
Callitris glaucophylla open woodland	1	17.0	17	3.0	3
Casuarina pauper / Alectryon oleifolius low open woodland	15	18.1	81	3.1	14
Eucalyptus coolabah / Eucalyptus largiflorens open woodland	2	9.0	14	4.5	6
Eucalyptus intertexta open woodland	5	18.6	56	2.8	10
Eucalyptus populnea open woodland	8	15.1	47	4.1	10
Flindersia maculosa low open woodland	9	19.8	69	3.6	12
Tall shrublands					
Acacia aneura tall open shrubland (hills)	9	21.1	85	1.7	11
Acacia loderi tall open shrubland	12	17.5	73	3.7	11
Acacia melvillei tall open shrubland	2	19.5	31	7.0	10
Eucalyptus socialis tall open shrubland (shrub understorey)	4	16.3	38	1.8	5
Eucalyptus socialis tall open shrubland (*Triodia* understorey)	2	29.0	40	1.0	1
Hakea leucoptera tall open shrubland	1	16.0	16	4.0	4
Hakea tephrosperma tall open shrubland	1	15.0	15	3.0	3
Low shrublands					
Acacia victoriae open shrubland	1	7.0	7	6.0	6
Eremophila / Dodonaea open shrubland	2	15.5	26	4.5	5
Grasslands					
Eragrostis australasica hummock grassland	5	12.0	33	5.4	13
Herblands					
Anthropogenic herbland	4	11.0	30	10.0	21
Lakebed herbland	2	12.0	21	7.5	12

Table 5. Conservation status of vegetation communities on Coonavitra based on Benson (2006)

Vegetation community	Area (ha) approx	Equivalent Benson (2006) vegetation community I.D	Conservation status (Benson 2006)
Woodlands			
Callitris glaucophylla open woodland	12	246	Least Concern
Casuarina pauper / Alectryon oleifolius low open woodland	14,067	58	Near Threatened
Eucalyptus coolabah / Eucalyptus largiflorens open woodland	56	38	Least Concern
Eucalyptus intertexta open woodland	140	108	Least Concern
Eucalyptus populnea open woodland	1,194	207	Least Concern
Flindersia maculosa low open woodland	4,230	144	Near Threatened
Tall shrublands			
Acacia aneura tall open shrubland (hills)	2,728	120	Near Threatened
Acacia loderi tall open shrubland	4,771	128	Endangered (*Threatened Species Conservation Act 1995*)
Acacia melvillei tall open shrubland	565	23	Endangered (*Threatened Species Conservation Act 1995*)
Eucalyptus socialis tall open shrubland	898	173/193	Near Threatened/Endangered
Hakea leucoptera tall open shrubland	1	199	Near Threatened
Hakea tephrosperma tall open shrubland	1	199	Near Threatened
Low shrublands			
Acacia victoriae open shrubland	37	139	Vulnerable
Eremophila / Dodonaea open shrubland	340	143	Least Concern
Grasslands			
Eragrostis australasica hummock grassland	61	24	Least Concern
Herblands			
Anthropogenic herbland	12	N/A	N/A
Lakebed herbland	67	166	

and weediness are additional factors which give some measure of vegetation condition. The communities of the Emmdale block are overall in very good condition despite the history of domestic grazing and suggests that this part of the Park has previously been subject to a relatively conservative grazing regime.

Conservation status of vegetation communities

The communities mapped correspond to those listed by Benson (1989) and Benson (2006) and nine of the communities recorded are listed as Endangered, Near Threatened or Vulnerable (Table 5).

Acacia loderi tall open shrubland and *Acacia melvillei* tall open shrubland are listed as Endangered Ecological Communities under the NSW *Threatened Species Conservation Act 1995.* Both communities are severely degraded over most of their range with old senescing trees and little regeneration (Benson 2006). The area of *Acacia loderi* within the northern block is almost certainly the largest intact example within a conservation reserve. There is evidence of regeneration of the overstorey which is rare over much of its range.

Eucalyptus socialis tall open shrubland is listed as Near Threatened and the area in the south of the Emmdale block is one of the northernmost occurrences. A small area consisting of very tall trees east of Coonavitra Homestead is probably an example of the extremely tall "tree mallee" Community 199 described by Benson (2006).

Acacia victoriae open shrubland is regarded as Vulnerable due to continual grazing by stock and rabbits and loss of the original *Callitris* overstorey (Benson 2006).

A number of woodland communities are regarded as Near Threatened largely due to past timber harvesting and lack of regeneration. These include *Casuarina pauper / Alectryon oleifolius* low open woodland, *Flindersia maculosa* low open woodland, *Acacia aneura* tall open shrubland (hills), and *Hakea leucoptera / Hakea tephrosperma* tall open shrubland.

The presence of these communities means that this part of Paroo Darling National Park makes a significant contribution to conservation of plant communities in NSW.

Plant species

236 species of vascular plants were recorded during this study. Though this survey was undertaken following three years of severe drought, good winter rains meant that a range of herbs and grass were recorded, but it is likely that many more species are still to be recorded.

The highest representation of these species recorded for the Coonavitra area was from the family Asteraceae (42) followed closely by Chenopodiaceae (39). The highest levels of introduced species were in communities subject to the greatest influence from water and disturbance. These include the Anthropogenic herblands around earth tanks, the Lakebed herbland associated with the Gulguy Waterholes and areas of *Eragrostis australasica* grassland associated with the natural wetlands of the Emmdale block. This is in accord with Westbrooke (1990) who found a high negative correlation between occurrence of introduced species and distance from water in studies at Mallee Cliffs National Park and Nanya Station. Whilst relatively large numbers of introduced species were also recorded for *Acacia victoriae* open shrubland and *Acacia melvillei* tall open shrubland, the number of quadrats sampled was limited.

None of the species recorded during this study are listed under the Commonwealth Government *Environment Protection and Biodiversity Conservation Act 1999* or the NSW *Threatened Species Conservation Act 1995.*

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References

Abraham, N. A. (1991) Geomorphology. In: *Lands of the North-West Corner of NSW – Technical Report No. 12.* Ed. P.L. Milthorpe, Soil Conservation Service of NSW.

Beadle, N.C.W. (1945). *Vegetation Map of Western New South Wales.* Soil Conservation Service, Sydney.

Beadle, N.C.W. (1948). *The Vegetation and Pastures of Western New South Wales with Special Reference to Soil Erosion.* Government Printer, Sydney.

Benson, J. (1989). Establishing priorities for the conservation of rare or threatened plants and plant associations in New South Wales. In: *The Conservation of Threatened Species and Their Habitats – Occasional Paper No. 2: 17–82.* Eds. M. Hicks and P. Eiser. Australian Committee for IUCN, Canberra.

Benson, J. S. (2006) New South Wales vegetation classification and assessment: Introduction – the classification, database, assessment of protected areas and threat status of plant communities. *Cunninghamia* 9(3): 331–382.

Benson, J. S., Allen, C. B., Togher, C. and Lemmon, J. (2006) New South Wales vegetation classification and assessment: Part 1 plant communities of the NSW Western Plains. *Cunninghamia* 9(3): 383–450.

Belbin, L. (1993). *PATN Manuals.* CSIRO Wildlife and Ecology, Lyneham, ACT.

Clewett, J. F., Clarkson, N. M., Owens, D. T. and Abrecht, D. G. (1994). *Australian Rainman: Rainfall Information for Better Management.* Department of Primary Industries, Brisbane.

Edwards, K. (1979). *Rainfall in New South Wales – With Special Reference to Soil Conservation – Technical Handbook No. 3.* Soil Conservation Service of New South Wales, Sydney.

Hardy, B. (1969). *West of the Darling*. Rigby, Adelaide.

Hazelton, P. (1977). *Wilcannia Land Systems Series Sheet SH 54–16.* New South Wales, Soil Conservation Service.

Heathcote, R. L. (1965). *Back of Bourke: A Study of Land Appraisal and Settlement in Semi-arid Australia.* Melbourne University Press, Carlton.

Hunter, J. and Fallavollita, E. (2003). *Vegetation and Floristics of Paroo Darling National Park – Thilta Karra Section.* Report to the New South Wales National Parks and Wildlife Service.

James, J. W. (1960). Erosion survey of the Paroo-Upper Darling region. Part III. Journal *of Soil Conservation Service of NSW* 16: 185–206.

Jervis, J. (1948). The west Darling country: its exploration and development. *Royal Australian Historical Society* 34: 65–88.

Kershaw, K. A. and Looney, J. H. H. (1985). *Quantitative and Dynamic Plant Ecology.* Edward Arnold, Caufield East, Victoria.

Knight, R. (1994). *Flora, Fauna and Wilderness Values of the Mount Glass and Peery Lake areas, Western New South Wales.* Report by the Wilderness Society to the Australian Heritage Commission, Sydney.

Lembit, R. (1993). *NSW Wilderness Review Stage II – Wilderness Area Investigation, Peery Lake and Mount Glass Study Areas – Botanical Survey Report.* Report to the Wilderness Society, Sydney.

Milthorpe, P. L. (1991). Vegetation. In: *Lands of the North–West Corner of NSW – Technical Report No. 12.* Ed. P.L. Milthorpe, Soil Conservation Service of NSW.

Morton, J. G. G. (1991). Geology. In: *Lands of the North-West Corner of NSW – Technical Report No. 12.* Ed. P.L. Milthorpe, Soil Conservation Service of NSW.

NPWS (2000). *File F/2835/vol. III – Peery.* New South Wales National Parks and Wildlife Service.

Pickard, J. and Norris, E. H. (1994). The natural vegetation of north-western New South Wales: notes to accompany the 1:1 000 000 vegetation map sheet. *Cunninghamia* 3(3): 423–464.

Pickard, J. (1990). Analysis of stocking records from 1884 to 1988 during the subdivision of Momba, the largest property in semi-arid New South Wales. *Proceedings of the Ecological Society of Australia* 16: 245–253.

Specht, R. L. (1970). Vegetation. In: *The Australian Environment.* Ed. G. W. Leeper. Melbourne University Press, Melbourne.

Stanley, R. J. (1991). Land settlement and development. In: *Lands of the North-West Corner of NSW – Technical Report No. 12.* Ed. P. L. Milthorpe. Soil Conservation Service of NSW.

Walker, P. (1972). *Barnato Land Systems Series Sheet SH 55–13.* New South Wales, Soil Conservation Service.

Westbrooke, M. E. (1990). Effects of grazing pressure on weediness in mallee communities: studies at Mallee Cliffs National Park and Nanya Station, south-western New South Wales. In: *The Mallee Lands: A Conservation Perspective.* Eds J. C. Noble, P. J. Joss and G.K. Jones. CSIRO, Melbourne.

Westbrooke, M., Gowans, S., Gibson, M., Callister, K., Palmer, G., Florentine, S., O'Keefe, M., Warnock, A. and Grundell, R. (2006). *The Vegetation of the Mount Murchison and Wilga areas, Paroo Darling National Park, Western New South Wales.* Report prepared for the New South Wales National Parks and Wildlife Service by the Centre for Environmental Management, University of Ballarat.

Westbrooke, M., Leversha, J., Gibson, M., Milne, R., Gowans, S., Harding, C., Callister, K. and O'Keefe, M. (2002). *The Vegetation of Peery National Park Western New South Wales.* Report prepared for the New South Wales National Parks and Wildlife Service by the Centre for Environmental Management, University of Ballarat, Victoria.

Westbrooke, M., Leversha, J., Gibson, M., O'Keefe, M., Milne, R., Gowans, S., Harding, C. and Callister, K. (2003). The vegetation of Peery Lake area, Paroo Darling National Park, western New South Wales. *Cunninghamia* 8(1): 111–128.

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Appendix 1: Flora species recorded within the Coonavitra area with frequency (%) of occurrence in communities

Nomenclature is according to Harden (1990–1993). * denotes introduced species.

Vegetation communities

Woodlands

1 *Callitris glaucophylla* open woodland
2 *Casuarina pauper / Alectryon oleifolius* low open woodland
3 *Eucalyptus coolabah / Eucalyptus largiflorens* open woodland
4 *Eucalyptus intertexta* open woodland
5 *Eucalyptus populnea* open woodland
6 *Flindersia maculosa* low open woodland

Tall shrublands

7 *Acacia aneura* tall open shrubland (hills)
8 *Acacia loderi* tall open shrubland
9 *Acacia melvillei* tall open shrubland
10 *Eucalyptus socialis* tall open shrubland (shrub understorey)
11 *Eucalyptus socialis* tall open shrubland (*Triodia* understorey)
12 *Hakea leucoptera* tall open shrubland
13 *Hakea tephrosperma* tall open shrubland

Low shrublands

14 *Acacia victoriae* open shrubland
15 *Eremophila / Dodonaea* open shrubland

Grasslands

16 *Eragrostis australasica* hummock grassland

Herblands

17 Anthropogenic herbland
18 Lakebed herbland

	Vegetation communities																	
Taxon, family and name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of quadrats	**1**	**15**	**2**	**5**	**8**	**9**	**9**	**11**	**2**	**4**	**2**	**1**	**1**	**1**	**2**	**5**	**4**	**2**
CONIFERS																		
Cupressaceae																		
Callitris glaucophylla	100	7																
FERNS																		
Adiantaceae																		
Cheilanthes austrotenuifolia							33											
Cheilanthes lasiophylla							22											
Cheilanthes spp.							11											
MONOCOTYLEDONS																		
Amaryllidaceae																		
Crinum flaccidum					13													
Asphodelaceae																		
* *Asphodelus fistulosus*								8										
Bulbine alata							11											
Bulbine bulbosa							11			25								
Cyperaceae																		
Eleocharis pallens																20		
Phormiaceae																		
Corynotheca lateriflora											100							
Poaceae																		
Aristida spp.																20		
Austrostipa eremophila				20														
Austrostipa nitida		7			13	22		17				100						
Austrostipa nodosa							11		100									
Austrostipa platychaeta						11												
Austrostipa scabra	100	93		60	100	89	78	75		100	100		100	100	50			50

	Vegetation communities																	
Taxon, family and name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of quadrats	**1**	**15**	**2**	**5**	**8**	**9**	**9**	**11**	**2**	**4**	**2**	**1**	**1**	**1**	**2**	**5**	**4**	**2**
Austrostipa scabra ssp *scabra*							11	8										
Austrostipa spp.					13	11		17										
Austrostipa trichophylla		7				11	11	8							50			
Brachyachne ciliaris											50							
Elymus scaber var. *scaber*		7					11											
Eragrostis australasica																100		
Eragrostis dielsii	100	7		20			11	8			50					20		
Eragrostis eriopoda							11											
Eragrostis setifolia				20	13													
* *Hordeum leporinum*		7	50		25	11								100	100	80	50	100
Lachnagrostis filiformis																80	75	50
Monachather paradoxa				40			33											
* *Schismus barbatus*		47	100	20	25	33								100	50			50
Thyridolepis mitchelliana				40			44											
Triodia scariosa										25	100							
* *Vulpia muralis*				20			11									20		
* *Vulpia* spp.				20			11											
Xanthorrhoeaceae																		
Lomandra spp.											50							
DICOTYLEDONS																		
Aizoaceae																		
Tetragonia eremaea		7				11		17								20		50
Amaranthaceae																		
Alternanthera nodiflora																20		
Ptilotus atriplicifolius var. *atriplicifolius*		27			25	22	44	33	50	50	50				50			
Ptilotus exaltatus var. *exaltatus*				20			11		50	25	100							
Ptilotus gaudichaudii							11											
Ptilotus gaudichaudii var. *goudchaudiii*							22											
Ptilotus nobilis var. *nobilis*					13													
Ptilotus polystachyus var. *polystachyus*	100	20		40		11	67			50	100		100		50			
Apiaceae																		
Daucus glochidiatus							44				50							
Asclepiadaceae																		
Leichardtia australis		7		20		11	11	8										
Rhyncharrhena linearis					13			8										
Asteraceae																		
Actinobole uliginosum		7													50			
Brachyscome ciliaris var. *lanuginosa*							11											
Brachyscome lineariloba		33			38	22	11	25	100		50	100	100		50			50
Bracteantha bracteata					13	11	11			25		100				20		
Calotis hispidula		20					22					100			50			
Calotis plumulifera		7		20							100							
Calotis scapigera							11											
Calotis spp.		7				22	22	17	100						50			
* *Carthamus lanatus*						11											50	
* *Centaurea melitensis*				20	13	11	11	33	50					100		60	100	50
Centipeda cunninghamii																20	75	
Centipeda spp.																	25	
Centipeda thespidioides																20		
Chthonocephalus pseudevax		20																
* *Cirsium vulgare*				20												20	50	
Euchiton spp.																	25	
Gnephosis foliata	100	27			13	22	11	42										
* *Hedypnois rhagadioloides* ssp *cretica*										25								
Helipterum hyalospermum							11											
Helipterum moschatum		7	50															
Ixiolaena leptolepis								8	50									
* *Lactuca serriola*																	25	
Leucochrysum molle							11											
Minuria cunninghamii					13													
Minuria integerrima																20		
Olearia pimeleoides										25								
Pseudognaphalium luteoalbum		7					11						100			20	25	
Pycnosorus pleiocephala		53	50	20	63	33		50	100	25		100	100			80	25	100
Pycnosorus pleiocephalus		20			13	22		25						100		20		
Rhodanthe corymbiflora	100	60		100	50	78	100	100	100	50	100	100	100	100		60	25	100

	Vegetation communities																	
Taxon, family and name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of quadrats	**1**	**15**	**2**	**5**	**8**	**9**	**9**	**11**	**2**	**4**	**2**	**1**	**1**	**1**	**2**	**5**	**4**	**2**
Rhodanthe floribunda		13	50		50		11	8							50		75	
Senecio glossanthus		13		20													25	
Senecio quadridentatus																	25	
Senecio spp.																	25	
* *Sonchus asper* subsp. *glaucescens*								8										
* *Sonchus oleraceus*						11											50	
Sonchus spp.		13														20		
Vittadinia cuneata		20				11	11		50									
Vittadinia dissecta											50							
Vittadinia spp.		7			13						50							
Waitzia acuminata		13		60		11	22			25	100							
* *Xanthium spinosum*																	75	
Boraginaceae																		
* *Echium plantagineum*	100	7		20		11	22	8					100			20	100	50
Halgania cyanea											100							
Heliotropium curassavicum																	25	
Heliotropium europaeum																	25	
* *Heliotropium supinum*																	25	
Omphalolappula concava		7																
Brassicaceae																		
* *Alyssum linifolium*		13	50		38	22		25	100			100			100	20		50
Arabidella trisecta				20				8										
* *Brassica tournefortii*	100	47		60	50	56	22	17	100	75	100	100	100		100	80	50	50
* *Carrichtera annua*	100	47	50	40	38	78	11	83	100	25		100				80	75	50
Harmsiodoxa brevipes var. *brevipes*	100	40		40	13		11		50						50			
Lepidium hyssopifolium				20													25	
Lepidium muelleri-ferdinandi											50							
Lepidium oxytrichum		33			25	56	67	25			50							
Lepidium papillosum								8	50									
Lepidium pseudohyssopifolium																60	25	50
Lepidium spp.		7						33								20		50
* *Sisymbrium erysimoides*		47	100		88	67		67	50					100		20	25	100
* *Sisymbrium irio*					13			17									50	50
* *Sisymbrium orientale*		7																
* *Sisymbrium* spp.									50									
Stenopetalum lineare		20		20	25	44	44	17	50	25		100			50			
Caesalpiniaceae																		
Senna form taxon 'artemisioides'		7		20			22	8			50							
Senna form taxon 'coriacea'								8										
Senna form taxon 'filifolia'		7		20		11				25								
Senna form taxon 'petiolaris'						11		17		50	100							
Campanulaceae																		
Wahlenbergia spp.							33											
Capparidaceae																		
Apophyllum anomalum		33	50	20	38	56		17										
Caryophyllaceae																		
* *Spergularia rubra*		7			25		11			25						40	25	50
Casuarinaceae																		
Casuarina pauper		93				33		17										
Chenopodiaceae																		
Atriplex angulata																20		
Atriplex eardleyae									50									50
Atriplex holocarpa								8										
Atriplex limbata		27	50	20	13	11		25	50									
Atriplex lindleyi																40	25	
Atriplex spp.		7			13											80		
Atriplex stipitata	100	47		20	75	78	56	75	50	75					50		25	
Chenopodium cristatum								8										
Chenopodium curvispicatum		47		20	13	22	11	33			50							
Chenopodium desertorum	100	53		60		33	33	17	50	75	100		100		50	20		
Chenopodium melanocarpum		7																
Dissocarpus paradoxus		80	100	40	100	100		92	100	100	50	100	100	100	100			
Einadia nutans		40		40	63	11	33	42							100			
Enchylaena tomentosa	100	67	100	20	63	78	67	67		25	50	100		100	50	20	50	
Maireana brevifolia					13	11		8						100				
Maireana georgei									50									
Maireana microcarpa								8								20		
Maireana pentatropis						11				50								
Maireana pyramidata		7				44		33		25								

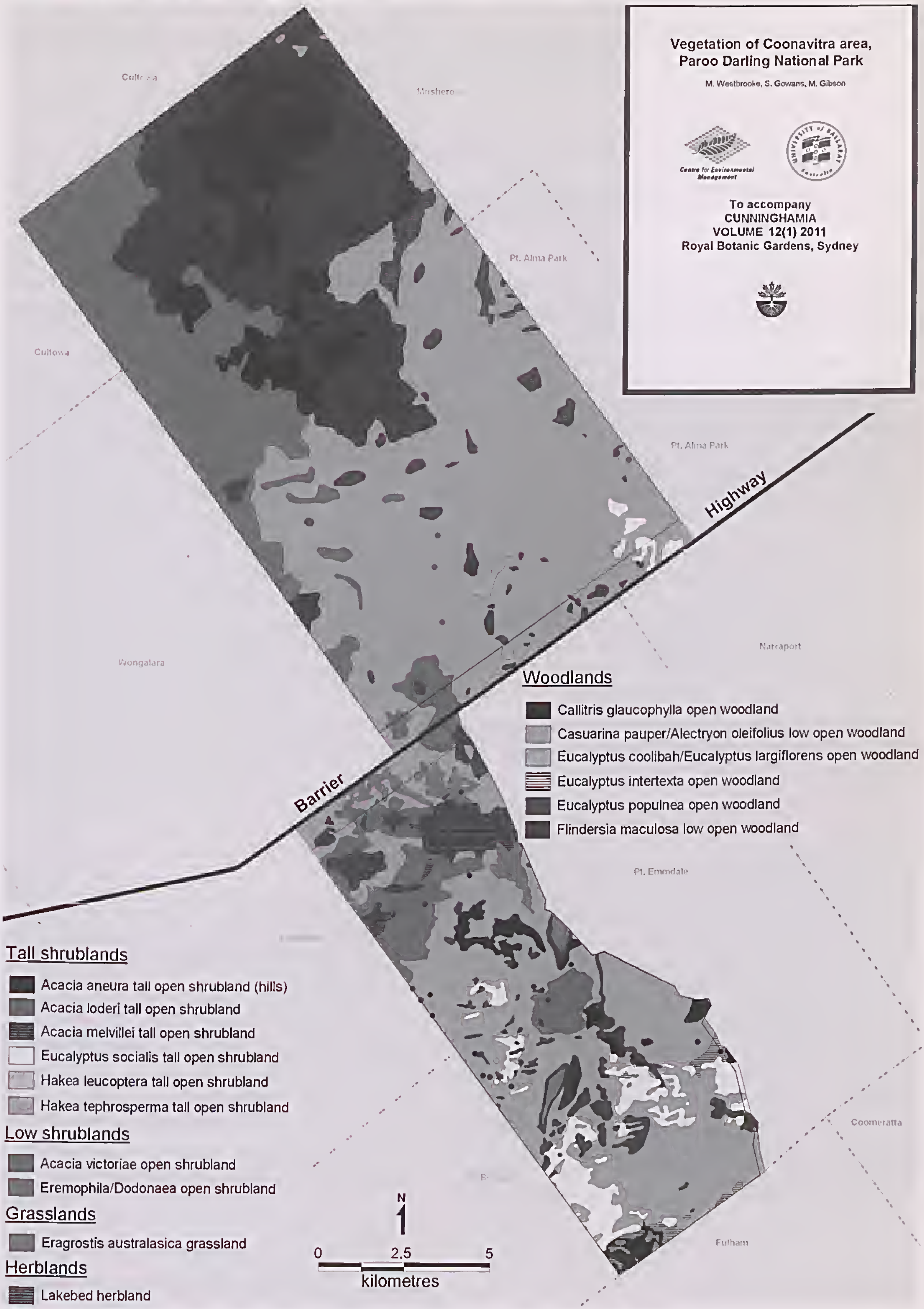
	Vegetation communities																	
Taxon, family and name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of quadrats	**1**	**15**	**2**	**5**	**8**	**9**	**9**	**11**	**2**	**4**	**2**	**1**	**1**	**1**	**2**	**5**	**4**	**2**
Maireana spp.						33	22	17										
Maireana triptera							11											
Maireana villosa							11											
Salsola kali var. *kali*	100	33			25	44		25	50		50		100					
Sclerochlamys brachyptera								8										
Sclerochlomys spp.																	25	
Sclerolaena bicornis							11											
Sclerolaena convexula		7		60			78				50	100						
Sclerolaena decurrens		7																
Sclerolaena diacantha		67		80	25	67	22			75	100		100		50			
Sclerolaena divaricata								8								20		
Sclerolaena intricata		7				11		17									50	50
Sclerolaena lanicuspis								17										
Sclerolaena longicuspis																		50
Sclerolaena muricata						11									50	40	50	50
Sclerolaena obliquicuspis	100	73		20	50	78	11	58	100	25		100	100		50			50
Sclerolaena parviflora				20						50	100					20		
Sclerolaena spp.			50			11		8							50			
Sclerolaena stelligera						11												
Sclerolaena tricuspis		7				22										60	25	50
Convolvulaceae																		
* *Convolvulus arvensis*		7																
Convolvulus clementii		7				11												
Convolvulus spp.		7						8	50			100						50
Crassulaceae																		
Crassula colorata								8										
Crassula spp.		27			13			8							50			
Fabaceae																		
* *Medicago laciniata*		53	100	40	100	33	33	92	100	25		100	100	100	100	60	50	100
* *Medicago minima*							11		50									50
* *Medicago polymorpha*		13														20	25	
Templetonia aculeata				20				8										
Templetonia egena										25								
Gentianaceae																		
* *Centaurium spicatum*																20		
* *Centaurium tenuiflorum*		7																
Geraniaceae																		
* *Erodium cicutarium*							11		50									
Erodium crinitum							11	8										50
Erodium spp.							11											
Goodeniaceae																		
Goodenia cycloptera	100																	
Goodenia gracilis							44									20		
Goodenia pinnatifida				20			22											
Goodenia spp.							11	17	50									50
Haloragaceae																		
Myriophyllum spp.																	25	
Myriophyllum verrucosum																	50	
Lamiaceae																		
* *Marrubium vulgare*																	25	
Prostanthera striatiflora							33											
* *Salvia verbenaca*		7		20				8	50					100			75	
Teucrium albicaule								8										
Teucrium racemosum		7			38												75	
Teucrium spp.					25													
Lauraceae																		
Cassytha spp.				20														
Loranthaceae																		
Amyema lucasii						56												
Amyema miquelii										50								
Amyema quandang var. *quandang*					25	11		33										
Lysiana exocarpi						11												
Malvaceae																		
Abutilon calliphyllum				20														
Abutilon fraseri		7		40		11	22											
Abutilon spp.							11	8										
Hibiscus sturtii spp. *sturtii*				20														
Malva australiana		13	50			11										60	50	100
* *Malva parviflora*																	25	

	Vegetation communities																	
Taxon, family and name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of quadrats	1	15	2	5	8	9	9	11	2	4	2	1	1	1	2	5	4	2
Sida cunninghamii				20			11											
Sida intricata		7		40			33	17	50		50							
Sida petrophila							11											
Sida spp.		7					11	8							100			
Mimosaceae																		
Acacia aneura		13		20		22	100				50							
Acacia colletioides										25								
Acacia loderi		13			13	22		100										
Acacia melvillei						11			100									
Acacia oswaldii		13		20		11												
Acacia tetragonophylla							22											
Acacia victoriae						22		25						100			25	
Myoporaceae																		
Eremophila duttonii							11											
Eremophila freelingii							11											
Eremophila glabra											50							
Eremophila goodwinii				20														
Eremophila longifolia				60		22	67	42		25	50							
Eremophila mitchellii							22											
Eremophila serrulata				20			22											
Eremophila spp.				20	13		22	8		25								
Eremophila sturtii	100	67		80	100	67	33	58	50	75								
Myoporum platycarpum		13				11					100							
Myrtaceae																		
Eucalyptus coolabah subsp. *coolabah*			50															
Eucalyptus intertexta				100														
Eucalyptus largiflorens			100		25													
Eucalyptus populnea subsp. *bimbil*			50		100													
Eucalyptus socialis										100	100							
Oleaceae																		
Jasminum lineare				20														
Oxalidaceae																		
Oxalis perennans						11	11											
Oxalis spp.											50							
Papaveraceae																		
* *Argemone ochroleuca* subsp. *ochroleuca*																	25	
Pittosporaceae																		
Pittosporum phylliraeoides				20	13					50								
Plantaginaceae																		
Plantago cunninghamii					13													
Plantago drummondii			50		13	11	11		50							60		50
Plantago turrifera		20		20		22	33								50			
Polygonaceae																		
Muehlenbeckia florulenta																20		
Rumex crystallinus																	25	50
Proteaceae																		
Grevillea huegelii											50							
Hakea leucoptera												100						
Hakea tephrosperma	100												100					
Ranunculaceae																		
Myosurus minimus var. *australis*																40		
Rutaceae																		
Eriostemon linearis							11											
Flindersia maculosa		7				100												
Geijera parviflora		7																
Santalaceae																		
Santalum acuminatum		7																
Sapindaceae																		
Alectryon oleifolius subsp. *canescens*		100		60	50	67		75	50			100	100		50			
Atalaya hemiglauca		7				11												

	Vegetation communities																	
Taxon, family and name	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Number of quadrats	**1**	**15**	**2**	**5**	**8**	**9**	**9**	**11**	**2**	**4**	**2**	**1**	**1**	**1**	**2**	**5**	**4**	**2**
Dodonaea viscosa subsp. *angustifolia*		33	50	60	50		22	25	50	50	100	100			100			
Dodonaea viscosa subsp. *angustissima*	100	13		20		22	11	8		25			100				25	
Scrophulariaceae																		
Stemodia florulenta																	50	
Solanaceae																		
Lycium australe						11												
* *Lycium ferocissimum*						11	11											
* *Nicotiana glauca*																	25	
Nicotiana velutina									50			100						
Solanum ellipticum							22											
Solanum esuriale							11	17										
Solanum ferocissimum				40			44	8			50							
Solanum spp.						22	22	8	50									
Thymelaeaceae																		
Pimelea spp.															50			
Pimelea trichostachya	100	13					11						100					
Zygophyllaceae																		
Zygophyllum ammophilum		7				11				25								
Zygophyllum apiculatum										25								
Zygophyllum aurantiacum								8		25								
Zygophyllum eremaeum		7		20	13	22	11	17	50	50	100							
Zygophyllum iodocarpum																		50
Zygophyllum ovatum		7								25								
Zygophyllum simile		7																
Zygophyllum spp.		13				11		8										

Appendix 2: Vegetation map of Coonavitra area, Paroo Darling National Park

Available in colour on the Cunninghamia website.


Vegetation of Coonavitra area, Paroo Darling National Park
M. Westbrooke, S. Gowans, M. Gibson
Centre for Environmental Management
University of Ballarat Australia
To accompany
CUNNINGHAMIA
VOLUME 12(1) 2011
Royal Botanic Gardens, Sydney
Cultowa
Mushero
Pt. Alma Park
Cultowa
Pt. Alma Park
Highway
Barrier
Narraport
Wongalara
Pt. Emmdale
Coomeratta
Fulham
Woodlands
Callitris glaucophylla open woodland
Casuarina pauper/Alectryon oleifolius low open woodland
Eucalyptus coolibah/Eucalyptus largiflorens open woodland
Eucalyptus intertexta open woodland
Eucalyptus populnea open woodland
Flindersia maculosa low open woodland
Tall shrublands
Acacia aneura tall open shrubland (hills)
Acacia loderi tall open shrubland
Acacia melvillei tall open shrubland
Eucalyptus socialis tall open shrubland
Hakea leucoptera tall open shrubland
Hakea tephrosperma tall open shrubland
Low shrublands
Acacia victoriae open shrubland
Eremophila/Dodonaea open shrubland
Grasslands
Eragrostis australasica grassland
Herblands
Lakebed herbland
N
0
2.5
5
kilometres

Saltmarsh of the Parramatta River-Sydney Harbour: determination of cover and species composition including comparison of API and pedestrian survey

R.J. Williams[1], *C.B. Allen*[2] *and J. Kelleway*[1]

[1]Industry and Investment NSW, Cronulla Fisheries Centre, PO Box 21, Cronulla, NSW 2230 AUSTRALIA;
[2]Royal Botanic Gardens, Sydney, NSW, 2000 AUSTRALIA

***Abstract*:** In 2004 coastal saltmarsh was listed as an Endangered Ecological Community under the New South Wales *Threatened Species Conservation Act*, but more information on the ecology of saltmarsh species as well as accurate maps of the cover of saltmarsh are needed. Large scale maps produced in the early 1980s and the mid 2000s were based on air photo interpretation with follow-up field checks, but to determine the ability of air photos to detect small patches of coastal saltmarsh, a pedestrian survey along the foreshore of the Parramatta River-Sydney Harbour estuary (33° 53'S; 151° 13'E) was commissioned. Ground-truth activity was partitioned into three levels of intensity. At the greatest level of intensity, many small patches obscured in the air photos by (mainly mangrove) canopy cover were resolved and joined to reveal larger patches of saltmarsh. Compared to the earlier maps these areas are considered to increase the total area of existing saltmarsh, but they also may in fact be areas of saltmarsh that have been recently invaded by mangroves, and ultimately, through shading and competition result in the loss of the saltmarsh species at these sites. Another 609 patches not seen on the air photos were located.

The pedestrian survey located 757 saltmarsh patches (70% of these were less than 100 m^2 in area) with a total area of 37.3 ha. Parramatta River, relative to the Lane Cove River, Middle Harbour Creek and Sydney Harbour, supports the most numerous and extensive patches: 461 patches (61% by number), 29 ha (78% by area). Most of the patches of saltmarsh (60%), as well as most of their area (76%), are located in the most upstream Riverine Channel geomorphic zone of the Parramatta River, followed by downstream zones Fluvial Delta and Central Mud Basin. The fewest patches (14) and smallest area (0.04ha) were in the Marine Tidal Delta. The 'conservation 'sensitive' species as well as some of the weed species also appeared to be restricted to the upper and middle parts of the estuary.

API is useful for broad assessments of estuarine saltmarsh, but pedestrian survey is needed to provide the finer scale detail necessary to locate small patches and to identify species composition especially for rare or weed species.

***Cunninghamia* (2011) 12(1) 29–43**

Introduction

Coastal saltmarsh is defined as an intertidal community dominated by halophytic herbs and low shrubs growing along the edge of the Australian continent (Adam 1990). The area of tropical saltmarsh exceeds that in temperate regions, but saltmarsh along the southeast coast is increasingly subject to human disturbance (Bridgewater & Cresswell 1999). At the structural and floristic levels there is some similarity between Australian saltmarshes and those elsewhere in the southern hemisphere, but less similarity with those in the northern hemisphere (Adam 1990).

The ecological role of Australian saltmarsh as a habitat for invertebrates, a foraging ground for fish, or a contributor to estuarine food chains has only recently been investigated (Laegdsgaard 2006). Some studies have focused on the subtropical saltmarshes of east coast Australia (e.g., Connolly 2003, Melville and Connolly 2003, Guest and Connolly 2004) while others have examined temperate saltmarshes further to the south (e.g., Connolly *et al.* 1997, Mazumder *et al.* 2006a, 2006b, Platell & Freewater 2009). Many species of non-vascular plants are found in saltmarsh, including epiphytic algae and diatoms, but the role of these in coastal ecology is also poorly understood (Adam 2002). Saintilan (2008) provides a review of many aspects of Australian saltmarshes. In 2004, because of threats to its long-term survival, Coastal Saltmarsh was listed as an Endangered Ecological Community (EEC) under the New South Wales *Threatened Species Conservation Act* 1995 (*TSC Act*).

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Threats to saltmarsh

The main threat to saltmarsh globally has been the reclamation of tidal lands for agricultural, urban or industrial purposes (Adam 2002), but the invasion of terrestrial plant species, and rises in sea level are now issues of concern for surviving remnants. A significant threat in Australia is from expansion of mangrove forest (Mitchell & Adam 1989, Saintilan & Williams 1999, 2000). Encroachment of mangroves into saltmarsh habitat may mean less area for saltmarsh. For the Parramatta River evidence from the 19th and early 20th centuries indicates that there was less mangrove cover relative to saltmarsh than at present (McLoughlin 2000). West *et al.* (2004) estimated that the cover of mangrove in the Parramatta River at 185 ha, a substantial increase from the 148 ha of West *et al.* (1985). This difference was not thought to be an increase in area but an enhancement in detection methods.

Downslope migration of *Phragmites australis* and freshwater reeds has also been observed (Wilton *et al.* 2003, Pickthall *et al.* 2004) and may threaten saltmarsh from its terrestrial side. The spread of *Phragmites* has been widely recorded in North America in recent decades where research has shown that the invading *Phragmites* is a foreign genotype and invasion is related to changed environmental conditions (Mitsch 2000, Stevenson *et al.* 2000, Weinstein *et al.* 2000). There is no evidence of exotic genotypes of *Phragmites* in Australia (although there has not been a proper survey) but at least in some cases, spread of *Phragmites* is clearly due to habitat alteration, such stormwater discharge.

Rise of sea level will have a significant impact on the distribution of plants living in and around estuaries (Vanderzee 1988, Williams 1990, Hughes 2003). Terrestrial vegetation, such as *Casuarina glauca* (Swamp She-oak) and *Melaleuca* species (Paperbarks) will be forced further upstream and upslope by the rise in mean sea-level. Mangrove and saltmarsh will also move further upslope from their present locations, as well as extend further upriver. Expansion of saltmarsh will be limited by topography and the presence of structures such as roads and buildings.

Human trampling can cause significant reductions in the number and cover of saltmarsh plants (Andersen 1995). In the Sydney region, recreational vehicles (4WD, trail bikes, BMX bikes) have been responsible for the loss of over 2.1 ha of saltmarsh along the Georges River (Kelleway 2004, 2005). Damage from unauthorised access has also been reported from the Parramatta River (K. Sommerville, pers. comm., 2006).

Mapping studies of New South Wales saltmarsh

An issue that has complicated wetland mapping at the whole-of-coast scale has been a lack of consensus on the number of species embraced within the term "saltmarsh". This is due, in part, to the definitional problem of what are "true" saltmarsh species relative to other species found in close association with saltmarsh. Saenger *et al.* (1977) identified 15 species in eastern Australia, Specht (1981) recorded 30 taxa and Adam *et al.* (1988) listed 120 possible taxa. Most saltmarshes are species poor (Adam *et al.* 1988), with richness increasing in the more southerly latitudes of Australia (Adam 1990).

Broad-scale mapping of vegetation has used remote sensing techniques based on air photos and satellite images, but the resolution of satellite images has not, until recently, been fine enough to differentiate small patches of estuarine macrophytes (Anstee *et al.* 2009). Mapping of saltmarsh for the whole of the NSW coast has used aerial photographic interpretation (API) in four general steps: obtain relevant aerial photos, extract boundary data to prepare presumptive maps, check the patch boundaries (polygons) in the field, and edit the presumptive maps to produce a final map.

West *et al.* (1985) produced the first maps of estuarine macrophyte cover for southeast Australia using API of photos taken in the late 1970s and early 1980s. They generated an atlas that showed cover of saltmarsh, mangrove and seagrass along the NSW coastline. The prime motive for the atlas was to assess the cover of seagrass within the context of the legislated responsiblities of the then NSW Department of Agriculture, but the extent of mangrove and saltmarsh were also denoted. The atlas revealed 58 km² of saltmarsh in 101 estuaries, but was not designed to provide details on species composition. The need to assess seagrass mandated the use of a boat for field checks but boat access through mangrove to saltmarsh to confirm presumptive locations would have been problematic at low tide and some patches assumed to saltmarsh may have been other types of vegetation. In circumstances where saltmarsh was hidden under mangrove canopy in aerial photos there may have been underestimations of area. In effect, both false positive and false negative observations may have ensued. In spite of these limitations the West *et al.* (1985) maps had wide use as planning and management documents by state and local government agencies.

API has been used to map the extent of saltmarsh in Sydney region estuaries including the Hawkesbury River (Williams & Watford 1997, Williams & Watford 1999, Williams & Thiebaud 2007); Parramatta River (West *et al.* 2004); Hacking River (Williams & Meehan 2004); and Carcel Bay, Pittwater (Wilton 1998). Some non-urban locations have also been mapped (Wilton *et al.* 2003), and an updated atlas for the entire coast of NSW is currently being prepared (West *et al.* in prep.). These studies were complemented by ground-truthing, but the intensity of field inspections varied and none of these studies show details of the occurrence of individual plant species.

Saltmarsh species in New South Wales estuaries

There is limited information about the distribution of saltmarsh species within individual NSW estuaries. In the Sydney region Clarke & Hannon (1967, 1969, 1970, 1971) identified seven species in a very detailed study at Towra Point, Clarke & Benson (1987) found the same seven species along the Lane Cove River, Clarke & Benson (1988) listed 25 species at Homebush Bay, and Pickthall *et al*. (2004) found 30 species along the Georges River. For Lake Illawarra, Yassini (985) listed 40 species, and for Jervis Bay Clarke (1993) listed 24 species. Clarke (1994) tabulated occurrences for other estuaries along the NSW south coast identifying up to six species at a number of locations. Characteristic saltmarsh species recognised by the NSW Scientific Committee (2004) in the Sydney region are listed in Table 1.

Except for the Georges River-Botany Bay study by Pickthall *et al*. (2004), no NSW studies have revealed species composition at the patch scale. To refine their study by overcoming locational vagaries such as "downstream" or "upper estuary", terms that, though in general use, have little ecological value due to the varying physical characteristics of estuaries, such as catchment size, surface area, water volume, tidal prism and sediment type, Pickthall *et al*. (2004) used a geomorphic framework (applying definitions of Roy 1984) to delimit the estuary into four geomorphic zones (from upstream to downstream): Riverine Channel, Fluvial Delta, Central Mud Basin, and Marine Tidal Delta.

Table 1. Characteristic saltmarsh species along the central coast of New South Wales (after the NSW Scientific Committee (2004). Six species (#) are considered of conservation significance due to their limited distribution in the Sydney metropolitan area. *TSC Act* = NSW *Threatened Species Conservation Act* 1995.

Scientific name	Family	Status in Sydney Region
Monocotyledons		
Baumea juncea	Cyperaceae	common
Gahnia filum	Cyperaceae	#rare
Juncus kraussii	Juncaceae	common
Triglochin striata	Juncaginaceae	common
Sporobolus virginicus	Poaceae	common
Zoysia macrantha	Poaceae	common
Juncus acutus	Juncaceae	common, introduced weed
Dicotyledons		
Lampranthus tegens	Aizoaceae	#rare
Halosarcia pergranulata subsp. *pergranulata*	Chenopodiaceae	#rare
Sarcocornia quinqueflora	Chenopodiaceae	common
Suaeda australis	Chenopodiaceae	common
Wilsonia backhousei	Convolvulaceae	#rare (listed as 'Vulnerable' in the *TSC Act*)
Selliera radicans	Goodeniaceae	#rare
Samolus repens	Primulaceae	common
Bacopa monniera	Scrophulariaceae	#rare

In each zone Pickthall *et al*. (2004) calculated the extent fof cover. *Sarcocornia quinqueflora* and *Sporobolus virginicus* were found throughout the estuary, but other species, such as *Gahnia filum*, *Selliera radicans* and *Wilsonia backhousei*, were found almost exclusively within the Fluvial Delta. That some species of saltmarsh were only found in the Fluvial Delta and not closer to the entrance was not thought to be due to human disturbance, but due to the natural distribution of particular ecological habitat conditions within the estuary. Pickthall *et al*. (2004) concluded that *Wilsonia backhousei*, *Selliera radicans* and *Gahnia filum* should be considered "sensitive" in conservation terms due to their limited presence relative to the other saltmarsh plants within the Georges River estuary.

These three species are also rare in the broader Sydney metropolitan region (*Australian Virtual Herbarium*, online) and the reduction in the distribution of *Wilsonia backhousei*, a prostrate mat-forming species, is such that it is now listed as "Vulnerable" under Schedule 2 of the NSW *TSC Act*. *Wilsonia backhousei* occurs at the northern end of its range in the Sydney region. In the 19th century it was extensive along the Sydney Harbour embayments (Hamilton 1919) but many of these areas were subsequently reclaimed. The historical record shows that *Selliera radicans*, another prostrate, mat-forming species, has also suffered a major decline in Parramatta River (Hamilton 1919, Adam *et al*. 1988).

Gahnia filum, a tall tussock sedge characteristic of the upper marsh fringe is at its most northern limit on the Georges River (Pickthall *et al*. 2004) and is markedly disjunct from the next nearest population further south in Jervis Bay (Clarke 1994). It is possible that *Gahnia filum* may have once been present along the foreshores of the Parramatta River, but there are no historical records to support this. Alternately, it may be spreading. P. Adam (pers. comm. (2007) has recently reported a small patch at Towra Point in Botany Bay that that has not been previously noted.

Flora surveys of Homebush Bay in Parramatta River (Clarke & Benson 1988; Adam 1996) have identified other species of conservation significance. *Lampranthus tegens*, a spreading, prostrate shrub is only found around the ports of NSW, appears to have been introduced from South Africa in the 19th Century, but has since become extinct in that country (S.W.J. Jacobs, pers. comm., 2007). Regardless of its history, attention should be given to all occurrences of this species in the Parramatta River-Sydney Harbour due to its extreme rarity.

Halosarcia pergranulata subspecies *pergranulata* is a native halophyte that grows in saline habitats including salt lakes in inland NSW. It has not been recorded in coastal saltmarshes outside of the Parramatta River and may possibly have been inadvertently transported to the Sydney area with livestock (the Homebush saleyards and abattoirs operated nearby in the 20th Century) or may have been naturally dispersed there. As an interesting disjunct occurrence it has conservation significance.

Due to their extreme conditions of salinity and waterlogging, saltmarshes are generally less prone to invasion by terrestrial weeds than other habitats. However the introduced Sharp Rush *Juncus acutus* is of concern along the NSW coast from the Macleay River to the Moruya River (*Australian Virtual Herbarium*, online). It is difficult, although possible, to eradicate this species, as experience at Sydney Olympic Park (Paul & Young 2006) and the Kooragang Wetlands (P. Svoboda, pers. comm., 2005) have shown. The Endangered Ecological Community listing for NSW coastal saltmarsh (NSW Scientific Committee 2004) identifies *Juncus acutus* as well as *Baccharis halimifolia* (Groundsel Bush), *Cortaderia selloana* (Pampas Grass) and *Hydrocotyle bonariensis* (Kurnell Curse) as weeds of particular consequence to saltmarsh.

Objectives

Investigations of saltmarsh cover in NSW have tended to fall into two categories: high-intensity investigations of single estuaries (e.g., Mitchell & Adam 1989), or low intensity investigations of all estuaries (e.g., West *et al.* 1985). Given the environmental sensitivity of coastal saltmarsh in NSW and possibly all of southeast Australia, accurate assessments of cover and species composition are needed. As a first step the methodology by which cover is determined needs to be resolved. While it is universally accepted that API must be complemented by field checking (ground-truth), there are no data to devise operating principles for such in-field observations. There are three likely pathways for field work. The cheapest of these is to inspect all presumptive polygons identified at the first stage of API and remove the incorrect ones. This approach will overlook small patches not captured in air photos and/or may ignore continuity, where canopy cover suggests several small patches but in fact a large contiguous patch may be present. A more intensive pathway is to enlarge the scope of the fieldwork (and hence the time-scale and budget) to locate all patches encountered. The third approach is to set a minimum size at which patches are to be mapped. In light of these alternatives, two major objectives were set for this study.

The first objective was to investigate ground-truth procedures that could be used to enhance presumptive API observations of saltmarsh. One subcomponent of this task was to determine the smallest patch size that could be detected with the current API tools; a second subcomponent was to determine the relative abundance of saltmarsh patches that might be hidden under the canopy of mangrove or other vegetation. At present, there is no remote sensing technology specifically adapted to locate hidden patches, but future application of spectral imaging systems might help to fill this gap. It was anticipated that field checks would reveal patches of vegetation incorrectly identified as saltmarsh (false positives) as well as add small patches not recognisable or resolvable in air photos (false negatives). The relative contribution of the two types of field survey to the total number as well as total area of patches could be assessed.

The second objective was to use pedestrian survey to identify the plant species composition, including weeds, within patches of saltmarsh. The size of patches in which the "sensitive" species occurred could then be determined.

A number of null hypotheses were tested:

- enhanced levels of pedestrian survey would not increase output
- species of native saltmarsh would be uniformly located throughout the estuary
- the degree of weed invasion of saltmarsh would be uniform throughout the estuary.

Methods

Study Site

The estuarine foreshore of Parramatta River-Sydney Harbour (33° 53'S; 151° 13'E) sits within a drowned river valley (Roy *et al.* 2001). Its catchment is small (347 km^2), with a total waterway area of 62 km^2 (NSW Dept of Natural Resources, online). We measured the length of the shoreline of the estuary as 361 km, but this length has changed considerably over the past 100 years, notably at Homebush Bay due to reclamation (Thorogood 1985, Rogers *et al.* 2005). Much of the estuary's northern foreshore is comprised of dissected Middle Triassic Hawkesbury Sandstone, whereas the western and southern shores are primarily alluvial material, being derived from Quaternary sands near the entrance, and shales and muds further upstream (Chapman & Murphy 1989).

To resolve distributional differences within the estuary, the geomorphic scheme devised by Roy (1984) and applied by Mesley (2003) to Sydney Harbour was used. In this scheme there are four types of geomorphic zone (from upstream to downstream): Riverine Channel, Fluvial Delta, Central Mud Basin, and Marine Tidal Delta (Figure 1). One zone, the Marine Tidal Delta, occurs only at the entrance to the estuary but there are multiple occurrences of the other zones. For mapping purposes the tidal barriers of Middle Harbour Creek, Lane Cove River and the Parramatta River were used as upstream margins.

Parramatta River-Sydney Harbour was chosen as the study site for a number of reasons. The river drains the centre of Australia's oldest (200 years) and largest city (Sydney, pop. 4,000,000 people) and expansion of waterfront accommodation has resulted in the destruction of many saltmarsh areas. Contemporary scientific collections (Hamilton 1919) and historical studies based on diaries, reports and artworks (McLoughlin 1987, 2000, 2002) indicate that saltmarshes were extensive in many of the embayments, creeks and intertidal flats of the estuary, particularly the upper

Parramatta River in the 19th Century. Mangroves appear to have been relatively restricted in abundance until the late 1880s but have expanded in response to land-use practices that enhanced sedimentation and provided new substrates (McLoughlin 2000). Recently saltmarsh sites have also been damaged by trail bikes (K. Sommerville, pers. comm., 2006).

The major conservation initiative associated with the Sydney 2000 Olympic Games dedicated extensive areas of tidal (and freshwater) wetlands as part of Newington Nature Reserve for conservation purposes. These wetlands can serve as reference sites to study future growth patterns of saltmarsh in the Parramatta River and elsewhere.

There are many current disturbances to the saltmarsh of Parramatta River-Sydney Harbour and an up-to-date map of saltmarsh, including the best possible depiction of small patches is needed. Two sets of API-derived maps have already been produced for Sydney Harbour to show the distribution of its estuarine macrophytes. West *et al.* (1985) found three patches of saltmarsh with a total area of 7.3 ha. West *et al.* (2004) identified 30 patches with an area of 9.6 ha. The objective of the former was to produce an indication of cover of saltmarsh for the whole of NSW, rather than a finely detailed description of distribution. Field checks were conducted in each study by boat, but otherwise there were major differences in approach. West *et al.* (1985) used the *camera lucida* technique, an analogue method in which a series of optics facilitated the tracing of a vegetation boundary from a black and white contact print of an aerial photograph to a 1: 25,000 scale reference map that poorly represents medium and small sized patches (see Williams *et al.* 2003 for further details). Additional refinements to the API technique became available to West *et al.* (2004) who used higher quality colour aerial photos, digitized, spatially referenced and analysed in geographic information system (GIS).

That individual patches of saltmarsh expanded over the ensuing years is unlikely, even though little is known about the growth patterns of saltmarsh species along southeast Australia. For instance Streever and Genders (1997) found competitive interaction between characteristic saltmarsh dominant shrub *Sarcocornia quinqueflora* and the exotic terrestrial grass *Stenotaphrum secundatum* to the former's detriment, while ongoing land-fill, vehicular and pedestrian damage and invasion by mangroves argue against any large-scale spread of saltmarsh. It is more likely the larger area determined by West *et al.* (2004) arose from the enhancement of the API methodology.

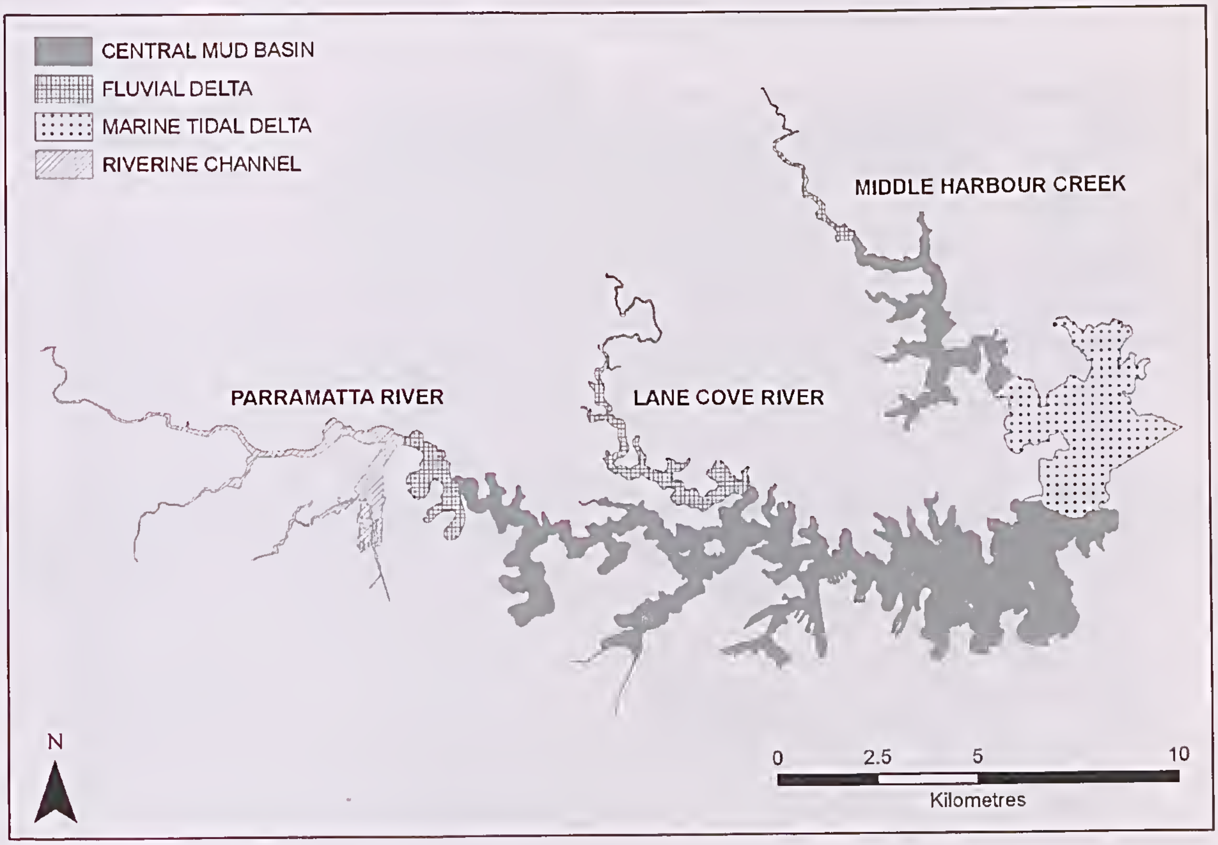

Fig. 1. Geomorphic zones in the estuary of the Parramatta River (after Mesley 2003).

Field survey

Coastal saltmarsh was defined as an intertidal community containing at least one or more of the 'Characteristic Species' listed by the NSW Scientific Committee (2004; Table 1) and/or species listed by Saintilan (2008, Appendix 2.1). Affiliated species observed growing in the intertidal region were also recorded. Elevation in terms of two vertical gradients was estimated.

Lower to middle marsh – growing below to within the tidal debris line (where present), with lowest areas often under the mangrove canopy.

Upper marsh – growing above the tidal debris line (where present), the highest elevation at which saltmarsh plants were observed growing.

It is likely that, particularly in the upper marsh fringe, *Zoysia macrantha* occurs intermingled with *Sporobolus virginicus* at some localities. It is possible, therefore, that some of the records for *Sporobolus virginicus* include *Zoyzia macrantha*, which because of the difficulty in distinguishing it from *Sporobolus virginicus* for most of the year is probably under-recorded in the Sydney region (P. Adam, pers. comm., 2007). Vegetatively the two grasses are very similar and hard to separate except when flowering. Field observations were carried out during the non-flowering season.

A pilot study in mid 2004 on the southwestern side of the estuary refined the method to be used in the pedestrian survey. The foreshore was traversed and each patch of saltmarsh was visited and its shape recorded on a 1: 25 000 topographic map and the approximate dimensions noted. Latitude and longitude were estimated from the topographic maps. Each patch was labeled with an alpha-numeric code in relation to the part of the estuary in which the patch was located. A condition assessment of each patch was made based on visual observation in relation to size, potential for tidal flushing and weediness, and a rating of poor, medium, good or excellent was given. Details on condition are reported in Kelleway *et al.* (2007).

The pilot study located 50 small patches along a 20 km section of foreshore (~6% of total shoreline length – 361 km). West *et al.* (2004) showed 30 patches of saltmarsh for the whole of the estuary; clearly, the pedestrian survey provided a greater level of detail.

The survey was suspended until more detailed 2003 (~150 mm spatial resolution) colour electronic images were obtained. Boundaries of saltmarsh were mapped via onscreen digitising with Arcview version 3.2. To ensure consistent spatial accuracy, all digitising was carried out at an onscreen scale of 1: 700. A presumptive (draft) image was produced from which field maps were printed such that assumed locations could be confirmed in the field.

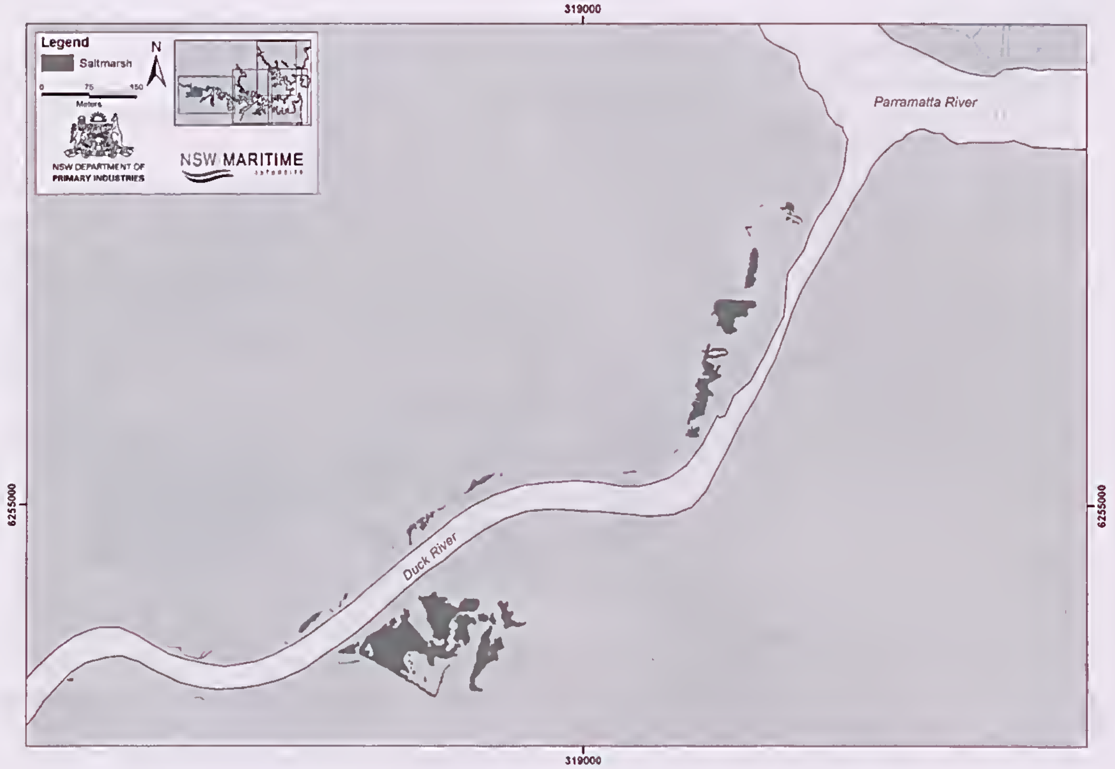

Fig.2. Saltmarsh of the estuary of the Parramatta River, 2005/06: magnification of a portion of the Duck River to provide an example of the detail available in the GIS shapefile generated for this project.

Field inspection was recommenced incorporating a global positioning system (GPS) to derive longitudes and latitudes. Other field observations were made as in the pilot study. Spurious patches were identified. Newly discovered patches too small to be identified in the images and omitted from the presumptive map were sketched to detail shape, size, orientation with GPS location, and proximity to landmarks, and were then digitised in GIS in relation to the 2003 colour imagery. In many cases canopy cover hid the true extent of the patch and so boundaries were modified on field maps as necessary. Twenty six sites were viewed tangentially due to access constraints (e.g. unexploded ordnance at Sydney Olympic Park). Fine-scale details (e.g., shape) were necessarily less well estimated at these locations. No island sites were visited. Edits to field maps were transferred to the presumptive digital image and all relevant data were assembled and cross checked in the GIS database. The area (in m^2) of each patch was calculated and tabulated.

Results

Comparison of API and pedestrian-derived maps

API of the 2003 digital image identified 411 patches of saltmarsh in Parramatta River-Sydney Harbour inclusive of Lane Cove River and Middle Harbour Creek (Table 2). The minimum size of patch in the API analysis was 1.33m^2. Field inspection revealed 155 (nearly 40%) of the 411 presumptive sites were false positive polygons, being comprised of reedlands (*Phragmites australis* or *Typha* spp.), mud, water, algal mats, lawn or anthropogenic structures. Field inspection of the 256 true patches revealed many were smaller parts of larger patches hidden under mangrove (mainly *Avicennia marina*) canopy. When the appropriate mergers were made, a subtotal of 148 patches was identified. One of these new large patches was an amalgam of 23 smaller patches that had been hidden or appeared to be separated under mangrove canopy. An additional 609 patches were newly discovered, ranging in size from 0.2 m^2 to 0.57 ha. When the appropriate mergers and additions were made, 757 patches were located.

The area determined from the presumptive map was 29.24 ha. Of this, 5.28 ha was incorrect, being that spurious area arising from the false positive polygons. It was then necessary to add the area obscured under canopy, and a subtotal of 29.83 ha was obtained. The area of the 609 newly discovered polygons was 7.43 ha, making a total area of 37.26 ha (Table 2). The field survey not only made a substantial contribution to the number of patches and the total area by eliminating falsely identified saltmarsh patches, but also by amalgamating patches that appeared to be disjunct, and by discovering many new, mostly very small, patches. Hence, the first null hypothesis was rejected.

Intensive field survey also discovered saltmarsh growing in non-typical areas (i.e., other than creek flats and heads of embayments). More specifically, saltmarsh was found on intertidal rock platforms in the bays and headlands of the lower estuary, particularly North Harbour. It was on this rock habitat that three previously unknown occurrences of the Vulnerable *Wilsonia backhousei* were located.

Figure 2 is from the final map and provides an example of the distribution of patches of saltmarsh of various sizes. An analysis of patch size in relation to connectivity, the ability of different technologies and imagery to find saltmarsh, and sea level monitoring implications is being conducted separately (Allen & Williams in prep.).

Distribution of saltmarsh in geomorphic zones

Parramatta River, relative to the Lane Cove River, Middle Harbour Creek and Sydney Harbour, supports the most numerous and extensive patches of saltmarsh: 461 patches (61% by number), 29 ha (78% by area) (Table 3). Most of the patches (60%), as well as most of the area (76%), are located in the most upstream Riverine Channel geomorphic zone of the Parramatta River, followed by downstream zones Fluvial Delta and Central Mud Basin. The fewest patches

Table 2. Stage by stage output from the mapping process for Parramatta River-Sydney Harbour estuary (2005/06) beginning with the presumptive saltmarsh map (API) and subsequent maps derived from the pedestrian survey by removing spurious patches, merging obscured patches, and then adding newly found patches of saltmarsh.
# = contiguous presumptive (256) polygons split by canopy cover merged into (148) whole polygons
* = additional 5.88 ha obscured (by canopy) in API

Stage of map production	Operation	Count of polygons	Area of polygons (ha)	Estimated analytical and field time (person days)
1st stage	Produce API presumptive map	411	29.24	5
2nd stage	Identify spurious polygons on presumptive map	-(155)	-(5.28)	15
3rd stage	Remove spurious polygons	256	23.95	1
4th stage	Merge polygons partially obscured	148#	29.83*	1
5th stage	Add new polygons observed during pedestrian survey	609	7.43	20
6th stage	Final map	757	37.26	42

Table 3. Number and area of saltmarsh patches in the Parramatta River-Sydney Harbour estuary by geomorphic zone, 2005/06.

	Upstream → → → → Downstream										
Geomorphic zone	**Riverine Channel**			**Fluvial Delta**				**Central Mud Basin**			**Marine Tidal Delta**	**Total (all zones)**
	Entire zone	Parramatta River Sub-catchment	Middle Harbour Creek Sub-catchment	Entire zone	Parramatta River Sub-catchment	Lane Cove River Sub-catchment	Middle Harbour Creek Sub-catchment	Entire zone	Parramatta River Sub-catchment	Middle Harbour Creek Sub-catchment	Entire zone	
Patch count (% of total count)	442 (60%)	442	0	201 (25%)	22	123	56	100 (14%)	78	22	14 (1.9%)	757 (100%)
Area (ha) (% of total area)	28.28 (76%)	28.73	0.00	7.34 (20%)	1.84	3.39	2.12	1.61 (4%)	0.62	0.99	0.04 (0.1%)	37.26 (100%)

(14) and smallest area (0.04ha) were found in the Marine Tidal Delta. This clear decrease in the number and size of patches towards the seaward zones, caused the second null hypothesis, that species of saltmarsh would be uniformly located throughout the estuary to be rejected. The absence of saltmarsh in the Riverine Channel of Middle Harbour Creek is presumably related to the small size of this zone in the incised bedrock. The equivalent zone in Lane Cove River has been extinguished by the placement of a weir and therefore contains no saltmarsh.

The count of patches showed that 70% were less than 100m^2 in area, with 38% less than 10m^2 (Table 4). In contrast, six patches greater than one hectare in size accounted for 41% of the total area; all were located on the southern shore, with four of them in the Sydney Olympic Park complex. "Sensitive" species were found in all size categories, but with a bias to the four middle size classes, particularly in the Riverine Channel (Table 4).

Distribution of saltmarsh species

Overall 29 native plant species were recorded in the 757 patches of saltmarsh of the Parramatta River-Sydney Harbour estuary. However, the number of species in each zone varied: 13 in the Riverine Channel, 11 in the Fluvial Delta, 10 in the Central Mud Basin, and six in the Marine Tidal Delta. Six were found in all geomorphic zones (Table 5). The Chenopods *Suaeda australis* (409 patches) and *Sarcocornia quinqueflora* (366 patches) occurred most commonly but were not found in the Marine Tidal Delta. Four other common species, *Tetragonia tetragonioides, Juncus kraussii, Sporobolus virginicus* and *Samolus repens* and two less common, *Baumea juncea* and *Ficinia nodosa,* were found in all zones. Occurrences for three of the latter four common species decreased downstream; the exception being *Samolus repens*, which was notably more prevalent in the Fluvial Delta. *Baumea juncea* was also more common in the Fluvial Delta and dominant at lower marsh elevations. *Tetragonia tetragonioides* grew almost exclusively in the higher marsh but was rarely extensive in any patch. The rush *Juncus kraussii* was more common in the Riverine Channel and Fluvial Delta than elsewhere and was dominant at upper marsh elevations. The most downstream geomorphic zone, the Marine Tidal Delta, had the fewest native species and was dominated by *Ficinia nodosa* and *Sporobolus virginicus.*

In the Georges River study, Pickthall *et al.* (2004) considered a number of saltmarsh species to be "sensitive" in conservation terms due to their apparent rarity and/or decline in the Sydney metropolitan region. We recorded five of these species in the Parramatta River-Sydney Harbour estuary: *Wilsonia backhousei, Lampranthus tegens, Halosarcia pergranulata* subsp. *pergranulata* , *Selliera radicans* and *Leptinella longipes* (Table 5).

The extensive Chenopod-dominated marshes of the Riverine Channel were the sites where patches of *Lampranthus tegens,* *Tecticornia pergranulata* subsp. *pergranulata*, and *Selliera radicans* were located exclusively. *Wilsonia backhousei* occurred more widely, but *Leptinella longipes* was only found in the Fluvial Delta. *Gahnia filum*, a species with limited distribution in the Sydney metropolitan region (P. Adam, pers. comm. 2007) was not found during this survey. The count of patches with "sensitive" species showed that 36% were less than 100m^2 in area, with 19% less than 10m^2 (Table 4).

Frequency of the sensitive species varied with patch size. Of the four species located exclusively in the Riverine Channel, *Lampranthus tegens* was found across a range of patch sizes as small as 1–10m^2, while *Halosarcia pergranulata* subsp. *pergranulata* and *Selliera radicans* were very rare and only recorded in one patch (0.1–1ha in size) (Figure 3a). Most of the *Wilsonia backhousei* (29 of 33 stands) was in the Riverine Channel but it was rare in patches less than 100m^2. There was also one stand in the Fluvial Delta (Figure 3b) and three stands in the Central Mud Basin (Figure 3c). The latter were small patches, growing high up on intertidal rock platforms, as opposed to the meadow-like stands found in the Riverine Channel and Fluvial Delta. *Leptinella longipes* was found only in the Fluvial Delta, and only in patches in the 10–1000 m^2 size categories (Figure 3b). Generally the sensitive species (except *Lampranthus*) were found in patches greater than 100 m^2; edge effects, overshading by taller species, and competition probably make smaller patches less suitable.

Some of the less frequent native species are not obligate saltmarsh species and can also be found in a range of habitats away from coastal saltmarsh, for example *Gahnia sieberana* and *Alisma plantago-aquatica* are also found in freshwater environments, and *Atriplex australasica* is found in inland NSW as well as scattered coastal locations (P. Adam, pers. comm. 2007). *Bacopa monniera*, while not a "true" species of saltmarsh plant may be found in brackish reaches of estuaries; in Sydney it approaches its global southern limit (P. Adam, pers. comm. 2007) (Table 5).

The occurrence of other native species immediately adjacent to saltmarsh assemblages was noted (Table 6). These plants favoured an upstream distribution, with five species found in the Riverine Channel, six in the Fluvial Delta, five in the Central Mud Basin and one in the Marine Tidal Delta. *Phragmites australis* and *Cynodon dactylon* were the most common of these species.

There were 17 exotic species associated with the saltmarsh of the Parramatta River-Sydney Harbour (Table 7). The prevalence (89 locations) of *Juncus acutus* was of great concern as it was sometimes observed to occur in dense aggregations, often in the larger patches of saltmarsh.

Table 4. Size categories of all patches of saltmarsh and those in which conservation sensitive species are found.

Saltmarsh species	**< 1 m^2**	**1–10 m^2**	**10–100 m^2**	**100 m^2–0.1 ha**	**0.1–1 ha**	**1–3 ha**	**Total**
No. of all saltmarsh patches of the given size							
Riverine Channel	9	141	146	104	37	5	**442**
Fluvial Delta	12	68	62	45	13	1	**201**
Central Mud Basin	11	38	33	15	3	0	**100**
Marine Tidal Delta	2	7	4	1	0	0	**14**
Total	**34**	**254**	**245**	**165**	**53**	**6**	**757**
Cumulative total	**34**	**288**	**533**	**698**	**751**	**757**	
% Cumulative	**4%**	**38%**	**70%**	**92%**	**99%**	**100%**	
Total Area m^2 **(%) of Total Area**	**24** **(0.01)**	**1255** **(0.3)**	**9567** **(2.6)**	**54327** **(15)**	**153416** **(41)**	**154036** **(41)**	**372625** **(100)**
Occurrences of "sensitive" species							
Riverine Channel	0	19	13	27	15	5	**79**
Fluvial Delta	0	0	3	2	1	0	**6**
Central Mud Basin	1	2	0	0	0	0	**3**
Marine Tidal Delta	0	0	0	0	0	0	**0**
Total	**1**	**21**	**16**	**29**	**16**	**5**	**88**
Cumulative total	**1**	**22**	**38**	**67**	**83**	**88**	
% Cumulative	**1%**	**25%**	**43%**	**76%**	**94%**	**100%**	

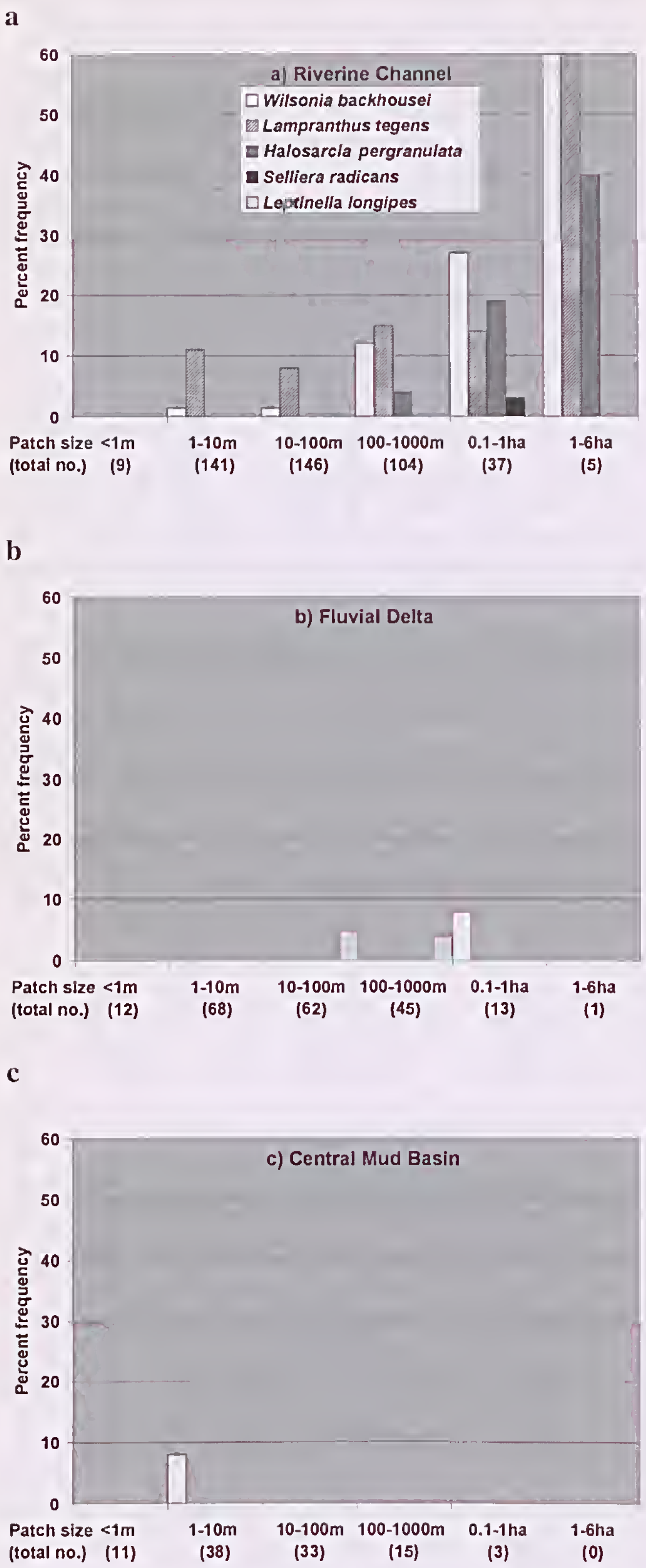

Fig. 3. Distribution of 'sensitive' saltmarsh species in Parramatta River-Sydney Harbour estuary (2005/06) in **a**) Riverine Channel (most upstream geomorphic zone), **b**) Fluvial Delta and **c**) Central Mud Basin.

The fact that it was concentrated in the Riverine Channel may indicate a physiological dependency, and this may be instructive in regard to its future management. Other exotic species appeared to favour upper estuarine locations and on the basis of these differential distributions, the third null hypothesis was rejected. The abundance of *Protasparagus aethiopicus* in the Fluvial Delta, and its distribution as the only weed species recorded from all zones, indicates the serious weed potential of this species. It has expanded considerably in abundance around the foreshores of Sydney Harbour and Pittwater in the last 30 years, in a range of sites but particularly in relatively undisturbed foreshore and bushland sites (D. Benson, pers. comm. 2010).

Discussion

Improvement in Air Photo Interpretation techniques

Over the past three decades there has been a progressive improvement in API techniques used to determine the extent of NSW estuarine vegetation. West *et al.* (1985) were limited to black and white air photos taken at a scale (1:16,000) that imposed limitations in finding small patches. West *et al.* (2004) were able to use 1:16,000 colour digital images, and undertook on-screen digitising at 1:1,500 scale, meaning that spatial resolution was of the order of 150mm (whereas for West *et al.* (1985) it was of the order of 2m). An increase in spatial resolution of airphotos enabled a 15 fold increase in number of patches in the latter study (from three to 30 patches) and a modest increase in the area of those patches (from 7.3 to 9.6 ha) (Table 8). Even with this enhancement in resolution, small patches of saltmarsh (in the order of 100m^2 or less) could not be identified.

The pedestrian survey in this study showed a 17-fold increase in number of patches (from 45 to 757), and a four-fold increase in area (9.6 ha to 37.3 ha) (Table 9). However, though the total area (37.3 ha) of saltmarsh found along the Parramatta River is substantially larger than revealed by previous studies, 99% of patches were less than one hectare in area, with 70% of the total being less than 100m^2 (Table 6). Only six patches greater than one hectare were identified. Ownership of these large patches is in the public domain (Kelleway *et al.* 2007), but management responsibility between government agencies for these, as well as the hundreds of other patches, requires further resolution.

This study also highlights discrepancies between three levels of pedestrian survey, any one of which must complement API. The lowest level of ground-truth, in which spurious patches are located and removed from a presumptive map, can only be considered appropriate if the objective of a mapping exercise is to generate a first approximation of the presence of saltmarsh, or if there is a need to clarify distributional data presented on other maps (e.g., West *et al.* 1985, West *et al.* in prep.). This approach eliminates false

Table 5. Number of occurrences of native species in saltmarsh patches in the Parramatta River-Sydney Harbour, 2005/06, by geomorphic zone. Most frequent species in each zone is in bold.
*=Species considered "Sensitive" in conservation terms.

Family	Species	"Sensitive"	Riverine Channel	Fluvial Delta	Central Mud Basin	Marine Tidal Delta	Total
Chenopodiaceae	*Suaeda australis*		**324**	54	31	0	409
Chenopodiaceae	*Sarcocornia quinqueflora*		**266**	53	**47**	0	366
Aizoaceae	*Tetragonia tetragonioides*		**201**	84	34	4	323
Juncaceae	*Juncus kraussii*		108	**104**	**49**	3	264
Poacae	*Sporobolus virginicus*		113	87	37	**8**	245
Primulaceae	*Samolus repens*		52	**113**	29	2	196
Chenopodiaceae	*Atriplex prostrata*		111	26	24	0	161
Juncaginaceae	*Triglochin striatum*		46	29	13	0	88
Cyperaceae	*Baumea juncea*		1	36	8	1	46
Cyperaceae	*Ficinia nodosa*		9	5	14	**11**	39
Chenopodiaceae	*Atriplex australasica*		23	10	0	0	33
Convolvulaceae	*Wilsonia backhousei*	*	29	1	3	0	33
Asteraceae	*Cotula coronopifolia*		11	3	4	0	18
Cyperaceae	*Isolepis cernua*		1	0	6	0	7
Amaryllidaceae	*Crinum pedunculatum*		0	2	2	0	4
Chenopodiaceae	*Atriplex semibacatta*		2	1	0	0	3
Cyperaceae	*Isolepis inundatus*		0	2	1	0	3
Lomandraceae	*Lomandra longifolia*		2	0	1	0	3
Juncaceae	*Juncus usitatus*		2	0	1	0	3
Scrophulariaceae	*Bacopa monniera*		1	0	1	0	2
Species restricted to one geomorphic zone							
Aizoaceae	*Lampranthus tegens*	*	50	0	0	0	50
Cyperaceae	*Bolboschoenus caldwellii*		14	0	0	0	14
Chenopodiaceae	*Halosarcia pergranulata* subsp. *pergranulata*	*	13	0	0	0	13
Asteraceae	*Leptinella longipes*	*	0	5	0	0	5
Cyperaceae	*Cyperus laevigatus*		0	0	2	0	2
Alismataceae	*Alisma plantago-aquatica*		2	0	0	0	2
Cyperaceae	*Fimbristylis ferruginea*		1	0	0	0	1
Juncaceae	*Juncus bufonius*		1	0	0	0	1
Cyperaceae	*Gahnia sieberana*		0	1	0	0	1
Goodeniaceae	*Selliera radicans*	*	1	0	0	0	1
Number of saltmarsh patches			**442**	**201**	**100**	**14**	**757**
Number of species	**30**	**5**	**25**	**18**	**19**	**6**	

positive patches (e.g., bare mud, freshwater reedlands, water, grasslands and anthropogenic structures) from preliminary map products and can substantially reduce API estimates of cover, but, while relatively inexpensive in terms of person days (Table 2), this method does not join patches in aerial photographs that appear disjunct due to canopy cover, nor does it locate medium and small size patches.

A higher level of fieldwork is necessary to show where mangrove or other canopy covers saltmarsh. That API was unable to determine understorey features was evidenced by the large number of patches (64%) that were growing completely or partially under canopy predominantly of mangrove, but also of swamp-oak and eucalypt canopies (Allen & Williams in prep.). In this study these areas are considered to increase the actual area of existing saltmarsh, but they may in fact also be areas of saltmarsh that have been recently invaded by mangroves, and ultimately, through shading and competition result in the loss of the saltmarsh species at these sites. These sites may provide warnings of future saltmarsh loss and the dynamics of species there should be further studied.

An even greater intensity of fieldwork will also increase resolution of the total number of patches in the estuary as well as the distribution of small patches that contain sensitive species (Table 4). Intensive field survey resulted in the discovery of saltmarsh growing in non-typical sites such as intertidal rock platforms: on these platforms three previously unknown occurrences of the listed Vulnerable species *Wilsonia backhousei* were located. The limited distribution of plants such as *Selliera radicans* might make it a candidate for a higher conservation status than it currently holds. We therefore advocate that the objectives of a mapping exercise must be clearly stated and the fieldwork geared to meet the objective. Ideally, high order ground truth exercises would include an inventory of species in each patch.

As remote sensing techniques evolve, it is likely the number of patches and total area of saltmarsh will be able to be tracked more efficiently. In future it will therefore be necessary to differentiate between increases in cover that come about from expansion of distribution, rather than by improvements in mapping methods. If this distinction is not made clear it is inevitable that erroneous conclusions might be drawn about "expansion" of saltmarsh when in fact addition resolution has been provided.

Saltmarsh distribution in Parramatta River-Sydney Harbour compared with Georges River

Both Sydney Harbour and the Georges River are drowned river valleys, and both systems include saltmarsh dominated by the subshrub *Sarcocornia quinqueflora* and grasslands of *Sporobolus virginicus*. In the former estuary *Wilsonia backhousei* was located primarily in the Riverine Channel (Table 5), a finding that parallels that of Pickthall *et al.* (2004). Similarly, *Selliera radicans* was only found in the upper estuary in both studies. The factors controlling the distribution of the rarer species may also be at play in determining the distribution of the introduced weed *Juncus acutus* as it also appears constrained to the brackish portions of both Sydney Harbour (Table 8) and the Georges River (Pickthall *et al.* 2004).

Even though adjacent, there are some notable differences between these estuaries. *Juncus kraussii* was more prevalent in the Georges River, being found at 51 of 70 sites (73%) with intertidal vegetation (Pickthall *et al.* 2004), while we found it at 264 sites out of 757 patches of saltmarsh (35%) in the Parramatta River (Table 5). Part of the explanation might be the greater resolution of our study, but *Juncus kraussii* grows at a high elevation in the tidal plain; in the Parramatta River it grew at a region most likely to have been lost to land reclamation and infilling. Alternatively the impact of freshwater floods that occur in the Georges River but not in the Parramatta River (which has a relatively small catchment), may maintain areas of brackish water suitable for this species.

The total area of saltmarsh in Parramatta River-Sydney Harbour (37 ha) is small compared to the Georges River-Botany Bay system (153 ha – Pickthall *et al.* (2004)) even though its shoreline length is distinctly shorter than that of the former. One possible reason for this is that shallow tidal flats as at Towra Point (now reserved as a Nature Reserve) are absent from the analogous part of Sydney Harbour. These distributional differences suggest that local sedimentary environments (determined by geomorphology) are important factors controlling the distribution of estuarine saltmarsh.

The geomorphic stratification of an estuary (*sensu* Roy 1984) applied in these studies can be readily applied to other NSW estuaries using aerial photographs, topographic maps and bathymetric contours, and if necessary can be confirmed with sediment sampling. Geomorphic zones so established can be used to test hypotheses about extent of cover and species composition, and to initiate distribution modelling. Zones can be used to stratify searches for selected species in unsurveyed estuaries, be applied in conservation management to control access, and be used to initiate the rehabilitation of degraded sites.

Saltmarsh in Parramatta River-Sydney Harbour

At the species level, differences in distribution within the estuary of the Parramatta River can be related to estuarine geomorphology. Marine Tidal Delta facies are comprised of calcareous sands of marine origin (Roy 1984). The Riverine Channel sediments are terrestrial alluvium derived from Hawkesbury Sandstone and Wianamatta Shale (Chapman & Murphy 1989). Fluvial Delta sediments will be similar to those of the Riverine Channel, whereas facies at the shoreline of Central Mud Basin environments will be marine sand at the downstream end and fluvial material upstream. How these different types of sediments affect the ecology of individual saltmarsh species is unknown; further distributional surveys, as well as manipulative experiments, are needed.

A factor that has modified the distribution of saltmarsh through its prehistory is the level of the sea. Over the past two and a half million years (Pleistocene era) sea level has risen and fallen many times of the order of 120–130m at intervals of roughly 100,000 years. Hence the valley of the Parramatta River has been regularly flooded and emptied of seawater, and the estuary is considered a drowned river valley (Roy 1984, Roy *et al.* 2001). Twenty thousand years ago, just prior to the most recent melting of the polar ice-caps, what we view today as the estuary was a small freshwater creek at the bottom of a sandstone gorge, and the estuarine section of the river and its associated vegetation was relocated some kilometres further east. As sea level rose and then stabilised about 6,000 years ago, new foreshore features were established. Seagrass colonised sandflats that had been deposited on slopes where terrestrial plants once grew, and mangrove and saltmarsh appeared on the tidal fringes. As this cycle has been repeated many times there is an implication that at least some species of saltmarsh have robust survival features. That saltmarsh appears to have recently colonised newly available substrata in at least one new location – Wentworth Point, reinforces this survival capacity. The Point was highly modified by land reclamation between the 1930s and 1970s (Rogers *et al*. 2005), but saltmarsh has established in locations not previously recorded (S. Paul, pers. comm. 2005).

Colonial settlement along the Parramatta River from the early 1800s brought clearing in the catchment, extraction of freshwater, emplacement of tidal barriers, discharge of effluent, and most importantly, reclamation of tidal wetlands. Historical studies (McLoughlin 1987, 2000, 2002), suggest that saltmarshes were extensive in the upper Parramatta River and much of the central part of the estuary that would have once supported extensive mudflats and saltmarshes has been infilled, with seawalls currently lining much of this shoreline. Sydney Harbour, the lower portion of the estuary, has the longest history of urbanisation and the smallest amount of saltmarsh. It is within this area that the earliest infilling of tidal land began. In places such as Rushcutters Bay no saltmarsh currently exists, despite the historical implications of its name. Foreshore reserves, including Lane Cove and Garigal National Parks, now protect small areas of saltmarsh along Lane Cove River and Middle Harbour, respectively.

Many of the present day saltmarshes of the Parramatta River are highly fragmented, evidenced in part by the large number of small patches recorded throughout the estuary. Fragmentation has resulted from structures such as seawalls and levees, from reclamation of land for residential and industrial purposes, and from the expansion of mangrove stands. As a result, the habitat potential of saltmarsh for many species of fauna, including snails, crabs, fish, birds and mammals will have been reduced (Laegdsgaard 2006).

The spread of the introduced Sharp Rush *Juncus acutus* is of major concern in the Parramatta as well as Georges River estuaries. Clarke and Hannon (1967, 1969, 1970, 1971) did not note its presence in the Sydney metropolitan region, nor did Clarke and Benson (1987) find it in the Lane Cove River. Kelleway *et al*. (2007) did not find it in Lane Cove River, but located it at 89 other locations in the upper river and along the southern shore including Homebush Bay. *Juncus acutus* was recorded at the latter location some decades ago (Clarke and Benson 1988). This weed should be contained, and future management should also deal with continued disturbances caused by unauthorised access and recreational use of saltmarsh.

The policy implications arising from the NSW *Threatened Species Conservation Act* require that all patches of coastal saltmarsh be located, and that the species within each patch are properly identified. Surveys based on API with limited ground truth do not achieve these ends but are useful for the monitoring of large-scale distribution and large-scale changes in cover. Not surprisingly, intensive pedestrian survey provides a better understanding of extent of cover, species composition and condition. Once fine-scale inventories of these features are established, they need to be repeated on a short-term basis to establish small scale temporal variability. Some progress has been made in developing cost-effective methods by which to undertake temporal assessments (e.g., Sainty & Jacobs 1997, Kessler 2004, 2006).

As a final note, while the generic term "coastal saltmarsh" has some value, it should be used only in limited circumstances. Saltmarshes are complex environments that require detailed levels of understanding of their distributional and assemblage characteristics to achieve management ends.

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Table 8. Comparison of specifications of three mapping studies of the cover of saltmarsh in the estuary of the Parramatta River-Sydney Harbour.

Study	Photo run	Airphoto type	Analytical technique	Air photo resolution	Date of field validation	Ground truth technique	Patch number	Area (ha)
West *et al*. (1985)	1978	Black and white contact prints	Analog (*Camera lucida*)	2000 mm	Jan. 1981	Boat survey	3	7.3
West *et al*. (2004)	2000	Colour contact prints	Digital (GIS)	300 mm	Dec. 2002 & Jan. 2003	Boat survey	30	9.6
This study	2003	Digital images	Digital (GIS)	150 mm	Sept. 2005 to June 2006	Pedestrian survey – removal of spurious patches	148	29.8
					Sept. 2005 to June 2006	Pedestrian survey – addition of newly discovered patches	757	37.3

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References

Adam, P. (1990) *Saltmarsh Ecology*. Cambridge University Press, Cambridge. 461 pp.

Adam, P. (1996) Saltmarsh Vegetation Study. In: *Homebush Bay Ecological Studies 1993–1995: Volume 2*. Olympic Coordination Authority. CSIRO Publishing, Melbourne.

Adam, P. (2002) Saltmarshes in a time of change. *Environmental Conservation* 29: 39–61.

Adam, P., N.C. Wilson & B. Huntley. (1988) The phytosociology of coastal saltmarsh vegetation in New South Wales. *Wetlands (Australia)* 7: 35–85.

Andersen, U.V. (1995) Resistance of Danish coastal vegetation types to human trampling. *Biological Conservation* 71: 223–230.

Anstee, J., E. Botha, R.J. Williams & A. Dekker. (2009) Study on the remote sensing of estuarine macrophytes and saltmarsh vegetation in Wallis Lake. CSIRO Water for a Healthy Country National Research Flagship report.

Australian Virtual Herbarium (AVH). [online] http://www.anbg.gov.au/avh/. [last visited 03/05/07].

Bridgewater, P. & I.D. Cresswell. (1999) Biogeography of mangrove and saltmarsh vegetation: implications for conservation and management in Australia. *Mangroves and Salt Marshes* 3: 117–125.

Chapman, G.A. & C.L. Murphy. (1989) Soil Landscapes of the Sydney 1: 100 000 Sheet. Soil Conservation Service of N.S.W., Sydney. 160 pp.

Clarke, L.D. & N.J. Hannon. (1967) The mangrove swamp and salt marsh communities of the Sydney district. I. Vegetation, soils and climate. *Journal of Ecology* 55: 753–771.

Clarke, L.D. & N.J. Hannon. (1969) The mangrove swamp and salt marsh communities of the Sydney district. II. The holocoenotic complex with particular reference to physiography and climate. *Journal of Ecology* 57: 213–234.

Clarke, L.D. & N.J. Hannon. (1970) The mangrove swamp and salt marsh communities of the Sydney district. III. Plant growth in relation to salinity and waterlogging. *Journal of Ecology* 58: 351–369.

Clarke, L.D. & N.J. Hannon. (1971) The mangrove swamp and salt marsh communities of the Sydney district. IV. The significance of species interaction. *Journal of Ecology* 59: 535–553.

Clarke, P.J. (1993) Mangrove, salt marsh and peripheral vegetation of Jervis Bay. *Cunninghamia* 3: 231–253.

Clarke, P.J. (1994) Chapter 2 Mangroves and Salt marshes. In. Jervis Bay Baseline Studies Final Report May 1994, Volume 1. CSIRO Division of Fisheries, North Beach, WA.

Clarke, P.J. & D.H. Benson. (1987) The Vegetation of Lane Cove State Recreation Area. Report by the Royal Botanic Gardens, Sydney. 83 pp. plus maps.

Clarke, P.J. & D.H. Benson. (1988) The natural vegetation of Homebush Bay, two hundred years of change. *Wetlands (Australia)* 8: 3–15.

Connolly, R. (2003) Differences in trophodynamics of commercially important fish between artificial waterways and natural coastal wetlands. *Estuarine Coastal and Shelf Science* 58: 929–936.

Connolly, R.M, A. Dalton & D.A. Bass. (1997) Fish use of an inundated saltmarsh flat in a temperate Australian estuary. *Australian Journal of Ecology* 22: 222–226.

Guest, M. A. & M. Connolly. (2004) Fine-scale movement and assimilation of carbon in saltmarsh and mangrove habitat by resident animals. *Aquatic Ecology* 38, 599–609.

Hamilton, A.A. (1919) An ecological study of the salt marsh vegetation of the Port Jackson district. *Proceedings of the Linnean Society of New South Wales* 44: 463–513.

Hughes, L. (2003) Climate change and Australia: Trends, projections and impacts. *Austral Ecology* 28: 423–443.

Kelleway, J. (2004) *Ecological impacts of recreational vehicles on saltmarshes of the Georges River, Sydney.* B.Env.Sc. Honours Thesis, University of New South Wales.

Kelleway, J. (2005) Ecological impacts of recreational vehicles on saltmarshes of the Georges River. Sydney. *Wetlands (Australia)* 22: 52–66.

Kelleway, J., R.J. Williams & C.B. Allen. (2007) An assessment of the condition of saltmarsh of the Parramatta River and Sydney Harbour, NSW. NSW Department of Primary Industries – Fisheries Final Report Series No. 90. 100 pp.

Kessler, M. (2004) Non-destructive rapid assessment methodology for saltmarsh in urban areas: Rational and implementation in Sydney Harbour Catchment. MSc Honours Thesis, University of New South Wales.

Kessler, M. (2006) Development of a non-destructive rapid assessment methodology for saltmarsh in urban areas, as tested in Sydney Harbour, NSW, Australia. *Wetlands (Australia)* 24: 1–40.

Laegdsgaard, P. (2006) Ecology, disturbance and restoration of coastal saltmarsh in Australia: a review. *Wetlands Ecology and Management* 14: 379–399.

Laedgsgaard, P., Kelleway, J., R.J. Williams & C. Harty. (2008) Chapter 9, Protection and management of coastal saltmarsh. In (Saintilan, N. ed.) *Australian Saltmarshes*. CSIRO Publishing, Melbourne.

Mazumder, D., N. Saintilan & R.J. Williams. (2006a) Trophic relationships between itinerant fish and crab larvae in a temperate Australian saltmarsh. *Marine and Freshwater Research* 57: 193–199.

Mazumder, D., N. Saintilan & R.J. Williams. (2006b) Fish assemblages in three tidal saltmarsh and mangrove flats in temperate NSW, Australia: a comparison based on species diversity and abundance. *Wetlands Ecology and Management* 14: 201–209.

McLoughlin, L.C. (1987) Mangroves and grass swamps: changes in the shoreline vegetation of the middle Lane Cove River, 1780s–1980s. *Wetlands (Australia)* 7: 13–24.

McLoughlin, L.C. (2000) Changes in estuarine wetlands distribution along the Parramatta River, Sydney, 1788–1940: implications for conservation and planning. *Cunninghamia*, 6(3): 579–610.

McLoughlin, L.C. (2002) Questioning assumptions and using historical data in developing an information base for estuarine management. *Coast to Coast 2002*: 281–285.

Meehan, A.J., R.J. Williams & F.A. Watford. (2005) Detecting trends in seagrass abundance using aerial photograph interpretation: problems arising with the evolution of mapping methods. *Estuaries* 28: 462–472.

Melville, J.A. & R.M. Connolly. (2003) Spatial analysis of stable isotope data to determine primary sources of nutrition for fish. *Oecologia* 136, 499–507.

Mesley, E. (2003) *Estuarine Geomorphology as a Surrogate for Ecological Habitat; Port Jackson Estuary, NSW*. BSc (Marine Science) Honours thesis, University of Sydney.

Mitchell, M.L. & P. Adam. (1989) The decline of saltmarsh in Botany Bay. *Wetlands (Australia)* 8: 55–60.

Mitsch, W.J. (2000) Self-design applied to coastal restoration. An application of ecological engineering. In *Concepts and Controversies in Tidal Marsh Ecology* (Weinstein, M.P. & D.A. Keeger eds), Kluwer: Dordrecht, pp. 554–564.

NSW Department of Natural Resources. (online) *Estuaries of New South Wales*. http://www.dnr.nsw.gov.au/estuaries/index.shtml. [last visited 03/05/07].

NSW Maritime. (2004) *Information Sheet: Sydney Harbour and Tributaries*.

NSW Scientific Committee. (2004) *Final determination on Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner bioregions – endangered ecological community listing*.

Paul, S. & R. Young. (2006) Experimental control of exotic spiny rush, Juncus acutus, from Sydney Olympic Park: 1. *Juncus* mortality and regrowth. *Wetlands (Australia)* 23: 1–12.

Platell, M.E. & P. Freewater. (2009) Importance of saltmarsh to fish species of a large south-eastern Australian estuary during a spring tide cycle. *Marine and Freshwater Research* 60: 936–941.

Pickthall, J., R.J. Williams, P. Adam & D. Connolly. (2004) Part 3, Estuarine vegetation. In *Shaping the Georges River Catchment; Georges River Catchment Environmental Study No. 2 – Biodiversity. Volume III – Aquatic Biodiversity* (Williams, R.J, A. Bryant & D. Ledlin, eds). PlanningNSW. Sydney. pp. 36–68 plus appendices. http://www.planning.nsw.gov.au/plansforaction/georges_biodiversity.html.

Rogers, K, N. Saintilan & D. Cahoon. (2005) Surface elevation dynamics in a regenerating mangrove forest at Homebush Bay, Australia. *Wetlands Ecology and Management* 13: 587–598.

Roy, P.S. (1984) New South Wales estuaries – their origin and evolution. In *Developments in Coastal Geomorphology in Australia* (Thom, B.G. ed). Academic Press, New York, pp. 99–121.

Roy, P.S., R. J. Williams, A. R. Jones, I. Yassini, P. J. Gibbs, B. Coates,R. J. West, P. R. Scanes, J. P. Hudson & S. Nichol (2001) Structure and Function of South-east Australian Estuaries. *Estuarine, Coastal and Shelf Science* 53: 351–384.

Saenger, P., M.M. Specht, R.L. Specht & V.J. Chapman. (1977) Mangal and coastal saltmarsh communities in Australasia. In *Wet Coastal Ecosystems* (V.J. Chapman ed). Elsevier, Amsterdam, pp. 293–345.

Saintilan, N. (2008) *Australian Saltmarshes*. CSIRO Publishing, Melbourne. 236 pp.

Saintilan, N. & R.J. Williams. (1999) Mangrove transgression into saltmarsh environments in south-east Australia. *Global Ecology and Biogeography* 8: 117–124.

Saintilan, N. & R.J. Williams. (2000) Short note: The decline of saltmarsh in southeast Australia: results of recent surveys. *Wetlands (Australia)* 18: 49–54.

Sainty, G.R. & S.W. Jacobs. (1997) *Hawkesbury – Nepean Saltmarsh Assessment. Report to Hawkesbury Nepean Catchment Management Trust*, Windsor.

Specht, R.L. (1981) Biogeography of halophytic angiosperms (saltmarsh, mangrove and sea-grass). In *Ecological Biogeography of Australia* (Keast, A. ed). Dr. W. Junk, The Hague, pp. 577–589.

Stevenson, J.C., J.E. Rooth, M.S. Kearney & K.L. Sundberg. (2000) The health and long term stability of natural and restored marshes in Chesapeake Bay. In *Concepts and Controversies in Tidal Marsh Ecology* (Weinstein, M.P. & Keeger, D.A., eds), Kluwer: Dordrecht, pp. 709–735.

Streever, W.J. & A.J. Genders. (1997) The effects of improved tidal flushing and competitive interactions at the boundary between salt marsh and pasture. *Estuaries* 20: 807–818.

Thorogood, C.A. (1985) Changes in the distribution of mangroves in the Port Jackson-Parramatta River estuary from 1931 to 1985. *Wetlands (Australia)* 5: 91–96.

Vanderzee, M.P. (1988) Changes in saltmarsh vegetation as an early indication of sea-level rise. In *Greenhouse: Planning for Climate Change* (Pearman, G.I. ed), CSIRO, Melbourne. pp. 147–160.

Weinstein, M.P., K.R. Philipp & P. Goodwin. (2000) Catastrophes, Near-catastrophes and the Bounds of Expectation: Success Criteria for Macroscale Marsh Restoration. In Weinstein, M.P. & D.A. Keeger (eds) *Concepts and Controversies in Tidal Marsh Ecology*. pp. 777–804. Klumer: Dordrecht.

West, G., R.J. Williams & R. Laird. (2004) Distribution of estuarine vegetation in the Parramatta River and Sydney Harbour, 2000. Final report to NSW Waterways Authority. NSW Fisheries Final Report Series No 70. 33 pp.

West, R.J., C.A. Thorogood, T.R. Walford & R.J. Williams. (1985) An estuarine inventory for New South Wales, Australia. Fisheries Bulletin 2. Department of Agriculture, New South Wales. 140 pp.

Williams, R.J. (1990) Projecting a Greenhouse rise in sea level on saltmarsh and mangrove habitats in New South Wales. *Wetlands (Australia)* 10: 15–19.

Williams, R.J. & A.J. Meehan. (2004) Focusing management needs at the sub-catchment level via assessments of change in the cover of estuarine vegetation, Port Hacking, NSW, Australia. *Wetlands Ecology and Management* 12: 499–518.

Williams, R.J. & I. Thiebaud. (2007) Hawkesbury-Lower Nepean aquatic habitat study: developing a monitoring framework. NSW DPI – Fisheries Final Report Series No. 91. 97 pp.

Williams, R.J. & F.A. Watford. (1997) *Change in the distribution of mangrove and saltmarsh in Berowra and Marramarra Creeks, 1941–1992*. Contract report by NSW Fisheries to Hornsby Shire Council. 21 pp.

Williams, R.J. & F.A. Watford. (1999) *Distribution of seagrass, mangrove and saltmarsh in the Cowan Creek Catchment Management Area*. Contract report by NSW Fisheries to SHURE and the Cowan Creek Catchment Management Committee. 27 pp.

Williams, R.J., A.J. Meehan & G. West. (2003) Status and trend mapping of aquatic vegetation in NSW estuaries. In *Coastal GIS 2003: an integrated approach to Australian coastal issues* (Woodroffe, C. D. & Furness, R. A., eds), Wollongong Papers on Maritime Policy, No. 14: 317–346.

Wilton, K. (1998) Changes in the mangrove and saltmarsh habitats of Careel Bay, Pittwater, NSW. MSc Thesis, School of Earth Sciences, Macquarie University, 216 pp.

Wilton, K., N. Saintilan & K. Rogers. (2003) Coastal wetland mapping using Geographic Information Systems. In *Coastal GIS 2003: an integrated approach to Australian coastal issues* (Woodroffe, C. D. & Furness, R. A., eds), Wollongong Papers on Maritime Policy, No. 14: 347–369.

Yassini, I. (1985) Foreshore vegetation of Lake Illawarra. *Wetlands (Australia)* 5: 97–117.

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Comparative floral presentation and bee-pollination in two *Sprengelia* species (Ericaceae)

*Karen A. Johnson** *and Peter B. McQuillan*

School of Geography and Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia.
*Corresponding author. E-mail: johnsonk@utas.edu.au

Abstract: Pollination by sonication is unusual in the Styphelioideae, family Ericaceae. *Sprengelia incarnata* and *Sprengelia propinqua* have floral characteristics that suggested they might be adapted to buzz pollination. Both species have florally similar nectarless flowers except that the stamens of *Sprengelia propinqua* spread widely after the flower opens, while those of *Sprengelia incarnata* cohere in the centre of the flower. To test whether sonication occurs, we observed bee behaviour at the flowers of both plant species, documented potential pollinators, and examined their floral and pollen attributes. We found that *Sprengelia incarnata* had smaller and drier pollen than *Sprengelia propinqua*. We found that *Sprengelia incarnata* was sonicated by native bees in the families Apidae (*Exoneura*), Halictidae (*Lasioglossum*) and Colletidae (*Leioproctus*, *Euryglossa*). *Sprengelia propinqua* was also visited by bees from the Apidae (*Exoneura*) and Halictidae (*Lasioglossum*), but pollen was collected by scraping. The introduced *Apis mellifera* (Apidae) foraged at *Sprengelia propinqua* but ignored *Sprengelia incarnata*. The two *Sprengelia* species shared some genera of potential pollinators, but appeared to have diverged enough in their floral and pollen characters to elicit different behaviours from the native and introduced bees.

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Introduction

The interactions between plants and pollinators are thought to be responsible for much of the diversity in angiosperm flower morphology, with many floral traits associated with particular animal behaviours (Lawrence et al., 2001). The flowers of buzz-pollinated plants are a notable example of this phenomenon. Furthermore, it has been proposed that flowers with small, dry pollen typical of buzz-pollination may represent a transitional stage to anemophily (Buchmann, 1983), and phylogenetic analyses suggest that the evolution of anemophily is more likely in groups with these traits (Culley et al., 2002).

Buzz-pollination is widespread among angiosperms. In the Australian flora, buzz pollination occurs in a range of genera including *Hibbertia* (Bernhardt, 1984; Bernhardt, 1986), *Thelymitra* (Bernhardt & Burns-Balogh, 1986), *Dianella* (Bernhardt, 1995), *Tetratheca* (Driscoll, 2003) and *Solanum* (Anderson & Symon, 1988). In the Styphelioideae, buzz-pollination has been confirmed for *Conostephium* and hypothesised for *Coleanthera myrtoides* Stschegl., *Rupicola* species, some *Leucopogon* species, *Richea milliganii* (Hook.f.) F.Muell., and *Sprengelia incarnata* Sm. (Houston & Ladd, 2002; Ladd, 2006). A range of floral characteristics that make up the traits of buzz-pollinated flowers have been elucidated (Buchmann, 1983; Harder, 1990). In the Australian taxa, buzz-pollinated flowers have been observed to have either exposed anthers (solanoid-type), or anthers hidden by the petals (Houston & Ladd, 2002). They typically have purple or blue petals and yellow anthers, or white petals and purple anthers (Houston & Ladd, 2002).

Buzz pollination occurs when a bee vibrates its thoracic flight muscles over the anthers, vibrating dry pollen onto its body (Harder, 1998; Houston & Ladd, 2002; Thorp, 2000). Buzz pollination or sonication of flowers by bees has been associated with porocidal anthers such as those in the Ericaceae. Most Ericaceae have two-lobed anthers that dehisce by introrse or terminal pores (Curtis, 1963; Stephens, 2004), an important preadaptation to buzz pollination in ericads such as *Vaccinium stamineum* L. (Cane et al., 1985). In contrast to the rest of the Ericaceae, the subfamily Styphelioideae (epacrids) generally have unilocular anthers

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that open by a single longitudinal slit (Curtis, 1963). However, the more basal genera, *Prionotes, Sprengelia* and *Richea* can have bilocular anthers that dehisce by a single slit (Crayn et al., 1998; Curtis, 1963) giving them characteristics of both ericads and epacrids.

Although the epacrids do not have apically porose anthers, the following characters are thought to make the widespread *Sprengelia incarnata* a candidate for sonication: nectarless flowers, anthers that dehisce introrsely from an elongated pore, and stamens that cohere and move as a unit (Houston & Ladd, 2002). With the exception of this last character, the Tasmanian endemic *Sprengelia propinqua* A.Cunn. ex DC. shares these attributes. Until recently, *Sprengelia incarnata* and *Sprengelia propinqua* were considered to be a single variable species (Buchanan, 2009; Buchanan, 2005; Curtis, 1963). However, the stamens in *Sprengelia propinqua* are free (Curtis, 1963), generally separating and spreading away from the central position after the flower opens.

Sonication has been observed to occur, regardless of different stamen morphologies and arrangements. For instance, in Java, *Xylocopa* bees buzz-pollinate three *Dillenia* species: *Dillenia suffruticosa* Martelli, where the stamens form a cone; and *Dillenia alata* (D.C) Martelli and *Dillenia philippinensis* Rolfe which have spreading stylar branches and both long and short stamens. On this evidence, *Sprengelia propinqua* may also be a candidate for sonication (Endress, 1997). We tested the hypothesis that the flowers of *Sprengelia incarnata* and *Sprengelia propinqua* are sonicated by native bees, examined floral morphology and pollen tackiness, and documented potential pollinators.

Methods

Study species and sites

Sprengelia propinqua was split from *Sprengelia incarnata* based on floral characters including free rather than cohering stamens and solely white flowers rather than bi-coloured pink and white flowers (Curtis, 1963; Walsh & Entwisle, 1996). The flowers of both species are hermaphroditic and nectarless. *Sprengelia propinqua* is a prominent species in moorland in southwest Tasmania while *Sprengelia incarnata* is a locally dominant species occurring throughout southeastern Australia and Tasmania. Observations on *Sprengelia incarnata* were made in buttongrass (*Gymnoschoenus sphaerocephalus* (R.Br.) Hook.f.) hummock sedgeland in the Peter Murrell Nature Reserve (43°00'45"S 147°18'43"E); in heathy *Eucalyptus tenuiramis* Miq. woodland with buttongrass present in the understorey, near Egg and Bacon Bay (43°14'45"S; 147°06'19"E); in similar vegetation on the Tasman Peninsula (43°01'23"S; 147°53'41"E) and in the Tasmanian Wilderness World Heritage Area (WHA) where it co-occurs with *Sprengelia propinqua* (42°57'18"S; 146°21'23"E). Observations on *Sprengelia propinqua* were made in buttongrass hummock sedgeland in the WHA (42°55'26"S; 146°21'34"E and 42°53'03"S; 146°22'52"E). An *Apis mellifera* L. (introduced honeybee) hive was present within 100 m of one *Sprengelia propinqua* study site.

For the purpose of our study plants closely fitting the descriptions of *Sprengelia incarnata* and *Sprengelia propinqua* were chosen for examination (Curtis, 1963; Walsh & Entwisle, 1996). Plants with intermediate floral morphology occur in the western study area. Vascular plant nomenclature follows Buchanan (2009); and author names follow those on The International Plant Names Index (www.ipni.org – accessed 19 May 2010). Monthly climate averages for rainfall, temperature, relative humidity and wind speed for our study sites are given in Table 1.

Floral morphology and pollen

Twenty specimens of each species were randomly selected from material housed at the Tasmanian Herbarium, Hobart (Appendix 1). Floral morphology was compared by measuring (to an accuracy of 0.5 mm) sepal, petal, style, stamen and anther length under a dissecting microscope. We used the Student's 2-sample t-test to determine if there were significant differences in the size of floral parts of *Sprengelia incarnata* and *Sprengelia propinqua*. All tests were performed in MINITAB 15.

To determine if there were any differences in the pollen of *Sprengelia incarnata* and *Sprengelia propinqua*, pollen samples from a live plant of each species (from Peter Murrell Reserve and WHA sites respectively) were examined under a Scanning Electron Microscope (SEM) at 5000x magnification at the Central Science Laboratory at the University of Tasmania. Maximum pollen grain diameter and tackiness were recorded. Tackiness in *Sprengelia* species was determined by whether pollen grains occurred separately (dry) or adhered to each other (sticky).

Flower visitors

Observations on flower visitors were made in person (while walking amongst flowers) and by video camera (Panasonic Digital Video Camera, model number NV-GS70, 1.7 mega pixel, 500x digital zoom) mounted on a tripod. A pollinator is defined as an animal that collects pollen and deposits it onto conspecific stigmas of other plants (Pellmyr, 2002). In contrast, a flower visitor is an animal at a flower that either does not contact the reproductive parts of the flower and/or does not travel between plants. For the purpose of our study, we defined a potential pollinator as an animal that we observed to contact the reproductive organs of a plant, actively removed pollen from the anthers, and move between conspecific species. In addition to the 'solanoid' *Sprengelia* flower-form that enables easy observation of insects contacting and removing pollen from the anthers, the *Sprengelia* pollen is different in colour from many of the sympatric co-flowering plant species including *Pimelea*, *Hibbertia*, *Aotus* and *Pultenaea*. Potential buzz pollination

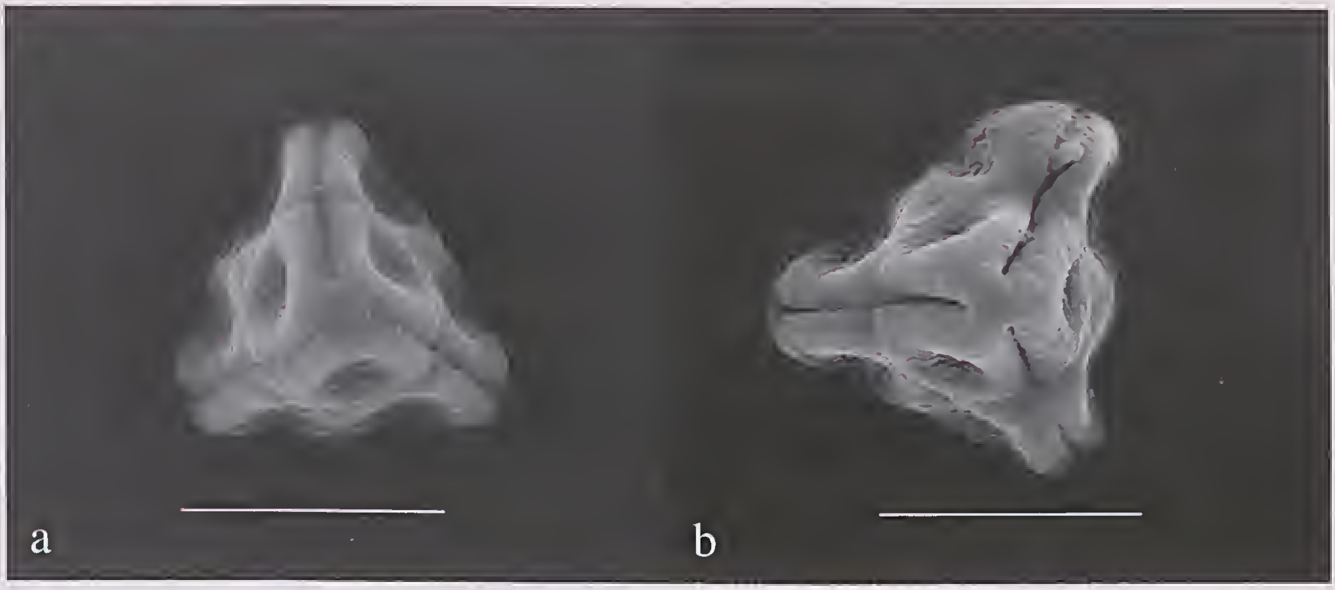

Fig. 1. *Sprengelia incarnata* pollen grain; B. *Sprengelia propinqua* pollen grain (scale bar approx. 20 µm)

was identified by a bee hunching over a flower's anthers with wings held back along the line of its body, and by an audible buzzing (Harder, 1998; Houston & Ladd, 2002; Thorp, 2000).

Observations were made on clear and relatively warm (> 18 °C) days. Observations were made on *Sprengelia incarnata* between 10 am and 4 pm on 9 Oct 2008, 29 Sep, 4 Oct, 10 Oct and 8 Nov 2009 during its peak flowering period. Observations were made on *Sprengelia propinqua* between 11 am and 3 pm on 23 Oct, 1 Nov, 5 Nov, 13 Nov, 19 Nov 2008 and 8 Nov 2009 during its peak flowering period.

Samples of the foraging insects were collected by netting, or captured straight into a plastic screw-top container wetted with ethanol. Insects were killed and stored in screw-top vials with 70% ethanol. Bees were identified to genus under a dissecting microscope using the key of Michener (1965) and the Hingston bee collection which holds specimens determined by Dr. Ken Walker (National Museum of Victoria). Together with potential pollinators collected during our survey, the Hingston collection is housed at the School of Geography and Environmental Studies Laboratory, UTAS. Flies were identified using Colless and McAlpine (1991) and butterflies using Braby (2004). Other invertebrates were identified using Zborowski and Storey (2003) and Daley (2007).

Results

Floral morphology and pollen

There was no overlap in the size of floral parts with *Sprengelia incarnata* being smaller in all parts (Table 2). Observation of pollen under the SEM revealed that the grains of *Sprengelia incarnata* occurred separately, indicating that they were dry, while the grains of *Sprengelia propinqua*, commonly adhered to form clumps indicating that the pollen was sticky. *Sprengelia propinqua* pollen was larger (*ca* 10%) than *Sprengelia incarnata* pollen, but had a similar morphology (Fig.1).

Table 1. Monthly climate averages for *Sprengelia* sites
(Note: All figures are from the closest climate stations on the Bureau of Meteorology website (www.bom.gov.au/weather/tas – accessed on 18 May 2010. These were Hobart, Dover, Port Arthur, and an average from the Strathgordon and Maydena Post Office climate sites).

Species and sites	Flowering time	Rainfall mm	Days rain ≥ 1 mm	Wind km/h 3 pm	Temp °C 3pm	% RH 3 pm
Sprenglia incarnata (Peter Murrell)	Sept–Oct	61	9	18	15	56
Sprenglia incarnata (Egg and Bacon Bay)	Sept–Oct	85	7	15	14	63
Sprenglia incarnata (Tasman Peninsula)	Sept–Oct	104	14	22	12	65
Sprenglia incarnata (WHA)	Sept–Oct	161	16	11	13	62
Sprengelia propinqua (WHA)	Oct–Nov	161	16	11	13	62

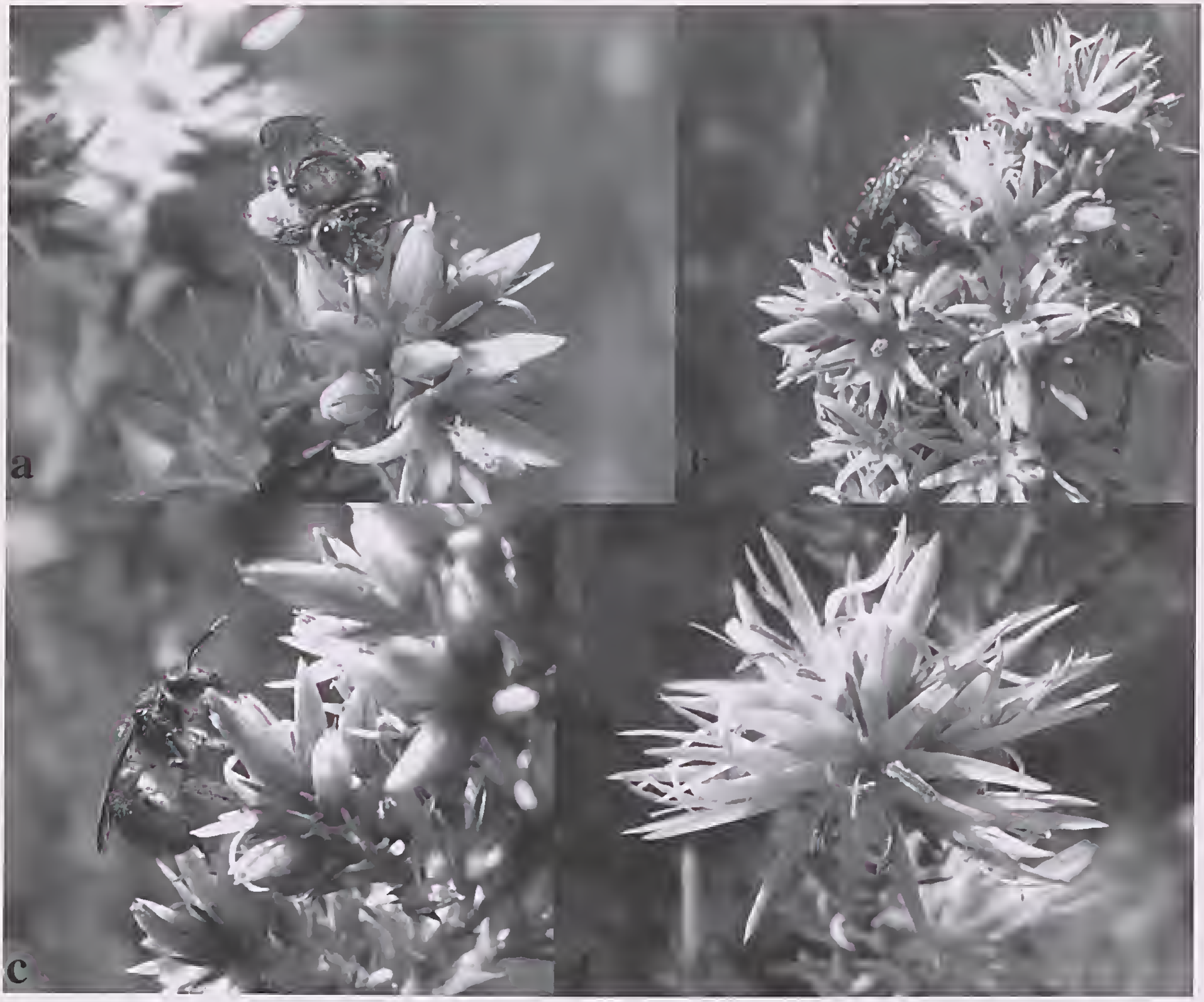

Fig. 2. *Lasioglossum* (Parasphecodes) bees on *Sprengelia incarnata* showing: A. folded wing position; B. hunched position during sonication; C. pollen accumulation; and D. anther position in *Sprengelia propinqua*

Table 2. Comparison of floral presentation in *Sprengelia incarnata* and *Sprengelia propinqua* in Tasmania

Floral presentation	***S. incarnata***	***S. propinqua***
Floral measurements (mean mm ± SE)*		
- Stamen	3.0 ± 0.04	4.8 ± 0.16
- Anther	1.6 ± 0.06	3.4 ± 0.15
- Style	3.7 ± 0.06	6.0 ± 0.90
- Petal	4.2 ± 0.09	6.6 ± 0.25
- Sepal	4.5 ± 0.09	7.2 ± 0.22
Flower colour	bicoloured pink and white	white
Flower position on stem	terminal	terminal
Flower heads	upright	upright
Stamen position	cohering in centre of flower	spreading widely as flower matures
Flowering time	Sep–Oct–Nov	Oct–Nov

**S. incarnata* and *S. propinqua* are significantly different in the size of all floral characters as follows: stamen ($t = -10.98$, $P < 0.001$, $DF = 22$), anther ($t = -11.42$, $P < 0.001$, $DF = 24$), style ($t = -11.30$, $P < 0.001$, $DF = 22$), petal ($t = -9.35$, $P < 0.001$, $DF = 24$), sepal ($t = -11.04$, $P < 0.001$, $DF = 25$).

Flower visitors

Sprengelia incarnata was repeatedly observed being sonicated by native bees (Fig. 2; Table 3). *Lasioglossum* species and *Exoneura* species were the main visitors (>100 observations). During sonication the bees collected large amounts of pale-coloured pollen on their legs and bodies and moved between *Sprengelia incarnata* plants. A thick layer of pollen was collected on the hind legs (femur, tibia and basitarsus) and abdominal sternites with additional pollen also scattered on body hairs outside these areas, including the head. Bees were observed to groom themselves after sonication, moving pollen from the thorax to abdomen with the aid of the front legs. The pollen-covered abdomen was observed to contact a flower's stigma in a manner consistent with a potential pollinator (Fig. 2C). Hoverflies (Syrphidae) were present at the study sites and two individuals contacted the anthers and appeared to collect pollen from *Sprengelia incarnata*. However, they were not observed to move between *Sprengelia incarnata* flowers. An introduced bumble bee queen, *Bombus terrestris* (L.), was observed to visit five flowers but was not observed to collect pollen. *Apis mellifera* (honeybees) were present and active at all sites during observations. They visited three flowers of *Sprengelia incarnata* over three separate occasions but did not collect pollen. Generally they flew past *Sprengelia incarnata* without landing on the flowers. They frequently collected pollen from sympatric plants including *Euryomyrtus ramosissima* (A.Cunn.) Trudgen, *Leucopogon collinus* (Labill.) R.Br., *Pimelea linifolia* Sm., *Pultenaea stricta* Sims, and *Aotus ericoides* (Vent.) G.Don when native bees were buzzing *Sprengelia incarnata*. Native bees also visited some of these sympatric plants.

Table 3. Potential pollinators and flower visitors for *Sprengelia incarnata* and *Sprengelia propinqua* in Tasmania
(i) = introduced, p = potential pollinator, + = buzz pollination, fv = flower visitor

Animal	***S. incarnata***	***S. propinqua***
Bees		
Euryglossa sp.	p +	
Exoneura sp.	p +	
Lasioglossum (Chilalictus) sp.	p +	p
Lasioglossum (Parasphecodes) sp.	p +	p
Leioproctus sp.	p +	
(i) *Apis mellifera* L.	fv	p
(i) *Bombus terrestris* (L.)	fv	p?
Flies		
Syrphidae	p?	p
Musca vetustissima Walker		fv
Tachinid fly (long-legged)		fv
Tachinid fly (short-legged)	fv	fv
Butterflies and moths		
Junonia villida (Fabricius)	fv	
Graphium macleayanus (Leach)		fv
Melitulias graphicata (Walker)		fv
Beetles		
Elateridae	fv	fv
Paropsis sp.	fv	
Chauliognathus tricolor (Castelnau)		fv
Other		
Diaea sp.	fv	fv
Pentatomidae (unidentified shield bug)	fv	fv
Thripidae (unidentified thrip)	fv	fv
Curculionidae (unidentified weevil)	fv	

No bees were observed to sonicate *Sprengelia propinqua*. *Apis mellifera* and *Lasioglossum* species were the main visitors (> 100 observations). Hoverflies (*Simosyrphus* species and *Melangyna* species) were also prominent visitors. *Exoneura* species was present but was only observed visiting *Epacris corymbiflora* Hook.f. Macleays' swallowtail butterfly (*Graphium macleayanus* (Leach)) visited *Sprengelia propinqua* and bobbed its head up and down in the same way it did to extract nectar from, and potentially pollinate, *Epacris corymbiflora*. On one occasion it probed a number of flowers on one plant. However, it was not observed to move between *Sprengelia propinqua* plants, making it a visitor, rather than a potential pollinator. In contrast, *Graphium macleayanus* regularly moved between *Epacris corymbiflora* plants (> 50 observations). *Graphium macleayanus* is known to be predominantly a nectar feeder, which makes it unlikely to be a regular forager on, and pollinator of, the nectarless *Sprengelia propinqua*. During observations on 23 Oct and 1 Nov 2008 at the site near the apiary, *Apis mellifera* was the only species active on *Sprengelia propinqua* and native bees were not observed.

Discussion

We have confirmed that pollen is collected from *Sprengelia incarnata* by sonication, as predicted by Houston & Ladd (2002) and scraped from *Sprengelia propinqua*. *Sprengelia propinqua* was not observed to be sonicated. Regardless of differences in flower size, pollen tackiness, stamen morphology and arrangement, *Sprengelia incarnata* and *Sprengelia propinqua* have overlapping floral visitor profiles with *Lasioglossum* bees being prominent potential pollinators of both plants.

Sonication of *Sprengelia incarnata* is undertaken by at least four native bee genera in Tasmania. With the exception of *Euryglossa*, bees from these genera are known to sonicate a range of plants in Australia. *Leioproctus* species have been observed to buzz *Conostephium drummondii* (Stschegl.) C.A.Gardner, *Conostephium pendulum*, *Conostephium minus* Lindl., *Conostephium roei* Benth. (Houston & Ladd, 2002) and *Hibbertia fasciculata* (Bernhardt, 1986). *Lasioglossum* species have been observed to buzz, *Conostephium roei* (Houston & Ladd, 2002), *Hibbertia stricta* (DC.) F.Muell. (Bernhardt, 1984), *Hibbertia fasciculata* DC. (Bernhardt, 1986), *Thelymitra nuda* R.Br. (Bernhardt & Burns-Balogh, 1986), *Melastoma affine* D.Don (Gross, 1993), *Dianella caerulea* var. *assera* R.J.F.Hend. (Bernhardt 1995) and *Tetratheca juncea* Sm. (Driscoll, 2003). *Exoneura* species are buzz-pollinators of *Dianella caerulea* var. *assera* (Bernhardt 1995) and *Tetratheca juncea* (Driscoll, 2003). Gross (1993) observed that bees from the genera *Amegilla*, *Lestis*, *Nomia* and *Xylocopa* were also capable of collecting pollen, via sonication, although they did not always do so. At least nine bee families are known globally to contain buzz-pollinators (Thorp, 2000).

Lasioglossum species and the introduced honeybee collected pollen from *Sprengelia propinqua* by scraping rather than sonication. Honeybees are not known to collect pollen by sonication (Thorp, 2000), and they ignored the flowers of *Sprengelia incarnata*. Honeybees have also been found to ignore the flowers of the buzz-pollinated *Conostephium pendulum* (Houston & Ladd, 2002) and *Dianella* species (Duncan et al., 2004). The introduced *Bombus terrestris* is a known buzz-pollinator (Dupont & Olesen, 2006) but was not observed to sonicate either *Sprengelia* species. *Exoneura* species has not been observed to visit *Sprengelia propinqua*, although it is present at these sites. *Euryglossa* species and *Leioproctus* species have not been observed at the *Sprengelia propinqua* sites and it is currently unknown if their geographic range extends into southwest Tasmania. Of the four native bee genera observed during survey, *Lasioglossum* species and *Exoneura* species are floral generalists but some *Euryglossa* species and *Leioproctus* species are known to be oligolectic (Houston, 2000). In Tasmania, these four bee genera represent important pollinators of a range of plant species, particularly from the Fabaceae and Ericaceae (Hingston collection held at University of Tasmania).

On some occasions pollinator activity was absent at *Sprengelia incarnata* even though known buzz-pollinators were scraping pollen from other plants nearby. The absence of pollinator activity on *Conostephium* flowers has also been observed on many occasions (Houston & Ladd, 2002). This could be a result of either pollinators seeking nectar, which is not offered by *Sprengelia*; or perhaps unfavourable climatic conditions for mobilising pollen. In general, foraging bees must either rely on honey reserves available prior to foraging – *Apis mellifera* can load up on supplies before leaving the nest – or divide their foraging bouts between nectarless and nectariferous flowers – like the majority of bee taxa (Bernhardt, 1989). In contrast to the polylectic nature of many native bee taxa, *Apis mellifera* workers usually collect pure pollen loads (Bernhardt et al., 1984). As the honeybee has a preference for foraging on some native plant species and not others, and is likely to collect pure pollen loads, it has the potential to impact not only on the floral evolution of individual native plant species, particularly those with nectarless flowers, but the entire native flora of Australia. Both *Sprengelia incarnata* and *Sprengelia propinqua* occur with co-flowering nectar-producing plants and honeybees were prevalent at all study sites; honeybee hives were present at the Tasmanian Wilderness World Heritage Area study sites.

In contrast to the other buzz-pollinated epacrid, *Conostephium*, which has hidden anthers and a pendulous, tubular corolla – *Sprengelia incarnata* resembles a 'solanoid' flower. However like *Conostephium*, *Sprengelia incarnata* does not have the usual colouration associated with many buzz-pollinated plants – yellow anthers and purple or blue petals (Houston & Ladd, 2002) – instead it has pale anthers and bicoloured white and pink petals. Given that a variety of floral morphologies and stamen arrangements are known to be sonicated, it is possible that the presence of drier (and possibly smaller) pollen enables collection by sonication at *Sprengelia incarnata*. It is probable that tacky pollen, such as that of *Sprengelia propinqua*, would be difficult to mobilise by sonication. In the Styphelioideae, the pollen of the buzz-pollinated *Conostephium pendulum* was found to be dry as was that of the readily mobilised, wind-dispersed pollen of *Richea procera* (F.Muell.)F.Muell and *Richea sprengelioides* (R.Br.)F.Muell. (Houston & Ladd, 2002; Ladd, 2006). This contrasts with the sticky pollen of the bird-pollinated *Prionotes cerinthoides* (Labill.)R.Br. (Johnson et al., 2010) and the likely mammal-pollinated, *Acrotriche serrulata* R.Br. (Johnson et al., 2011).

Houston & Ladd (2002) observed that the buzz-pollination syndrome was present in phylogenetically separated parts of the Styphelioideae. They confirmed that pollen was collected via sonication from *Conostephium* in the tribe Styphelieae. Now, we have confirmed that pollen is also collected by sonication from *Sprengelia incarnata* in the tribe Cosmelieae. Thus, there has been independent development of flowers suitable for this form of pollen collection in the Styphelioideae. Although there is currently no phylogenetic hypothesis for the genus *Sprengelia*, it is possible that *Sprengelia incarnata* with a floral form suitable for sonication was derived from a *Sprengelia propinqua*-type ancestor exhibiting the more common tacky pollen and spreading anthers. The intergradation of floral presentation between these two species could be viewed as supporting evidence for such a hypothesis.

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References

Anderson, GJ, D Symon 1988 Insect foragers on *Solanum* flowers in Australia. Annals of the Missouri Botanical Garden 75: 842–852.

Bernhardt, P 1984 The pollination biology of *Hibbertia stricta* (Dilleniaceae). Plant Systematics and Evolution 147: 266–277.

Bernhardt, P 1986 Bee-pollination of *Hibbertia fasciculata* (Dilleniaceae). Plant Systematics and Evolution 152: 231–241.

Bernhardt, P 1989 The floral ecology of Australian *Acacia*. pp. 127–155. In, Advances In Legume Biology, Stirton, CH and Zarucchi, JL Monographs in Systematic Botany from the Missouri Botanical Garden, St. Louis, Mo.

Bernhardt, P 1995 The floral ecology of *Dianella caerulea* var. *assera* (Phormiaceae). Cunninghamia 4: 1–17.

Bernhardt, P, P Burns-Balogh 1986 Floral mimesis of *Thelymitra nuda* (Orchidaceae). Plant Systematics and Evolution 151: 187–202.

Braby MF 2004 The complete field guide to butterflies of Australia. CSIRO Publishing Victoria, Australia.

Buchanan, AM 2005 A census of the vascular plants of Tasmania and index to the student's flora of Tasmania. Tasmanian Museum and Art Gallery, Hobart.

Buchanan, AM 2009 A census of the vascular plants of Tasmania. www.tmag.tas.gov.au. Accessed January 2011.

Buchmann, SL 1983 Buzz pollination in angiosperms. *in*: CE Jones, RJ Little eds. Handbook of experimental pollination biology. van Nostrand, New York.

Cane, JH, GC Eickwort, FR Wesley, J Spielholz 1985 Pollination ecology of *Vaccinium stamineum* (Ericaceae: Vaccinioideae) American Journal of Botany 72: 135–142.

Chess, SKR, RA Raguso, G LeBuhn 2008 Geographical divergence in floral morphology and scent in *Linanthus dichotomus* (Polemoniaceae) American Journal of Botany 95: 1652–1659.

Colless, DH, DK McAlpine 1991 Diptera. In CSIRO The Insects of Australia: a textbook for students and research workers Vol. 2. Melbourne University Press, Carlton.

Crayn, DM, KA Kron, PA Gadek, CJ Quinn 1998 Phylogenetics and evolution of epacrids: A molecular analysis using the plastid gene rbcl with a reappraisal of the position of *Lebetanthus*. Australian Journal of Botany 46: 187–200.

Culley, TM, SG Weller, AK Sakai 2002 The evolution of wind pollination in angiosperms. Trends in Ecology & Evolution 17: 361–369.

Curtis, WM 1963 The student's flora of Tasmania. Government Printer, Hobart.

Daley, E 2007 Wings: an introduction to Tasmania's winged insects. 40 Degrees South Pty Ltd, Hobart.

Driscoll, C 2003 Pollination ecology of *Tetratheca juncea* (Tremandraceae): Finding the pollinators. Cunninghamia 8: 133–140.

Duncan, DH, AB Nicotra, SA Cunningham 2004 High self-pollen transfer and low fruit set in buzz-pollinated *Dianella revoluta* (Phormiaceae). Australian Journal of Botany 52: 185–193

Dupont, YL, JM Olesen 2006 Andromonoecy and buzz pollination in *Solanum* species (Solanaceae) endemic to the Canary Islands. Anales del Jardin Botanico de Madrid 63: 63–66.

Endress, PK 1997 Relationships between floral organization, architecture, and pollination mode in *Dillenia* (Dilleniaceae). Plant Systematics and Evolution 206: 99–118.

Gross, CL 1993 The breeding system and pollinators of *Melastoma affine* (Melastoma taceae); A pioneer shrub in tropical Australia. Biotropica 25(4): 468–474.

Harder, LD 1990 Pollen removal by bumble bees and its implications for pollen dispersal. Ecology 71: 1110–1125.

Harder, LD 1998 Pollen-size comparisons among animal-pollinated angiosperms with different pollination characteristics. Biological Journal of the Linnean Society 64: 513–525.

Houston, TF 2000 Native bees on wildflowers in Western Australia. Special Publication No. 2 of the Western Australian Insect Study Society Inc., Perth.

Houston, TF, PG Ladd 2002 Buzz pollination in the Epacridaceae. Australian Journal of Botany 50: 83–91.

Johnson, KA, PB McQuillan, JB Kirkpatrick 2011 Nocturnal mammals, diurnal lizards and the pollination ecology of the cryptic flowering *Acrotride serrulata* (Ericaceae). International Journal of Plant Sciences 172(2): 173–182.

Johnson. KA, PB McQuillan, JB Kirkpatrick 2010 Bird pollination of the climbing heath *Prionotes cerinthoides* (Ericaceae). International Journal of Plant Sciences 171: 147–157.

Ladd. PG 2006 Is there wind pollination in the southern heaths (Styphelioideae, Ericaceae)? Botanische Jahrbücher für Systematik, Pflanzengeschichte und Pflanzengeographie. Leipzig 127: 57–67.

Lawrence, D, NM Harder, CY Williams, J Nelson, WA Nelson 2001 The effects of floral design and display on pollinator economics and pollen dispersal. *in*: L Chittka, JD Thomson eds. Cognitive ecology of pollination. Cambridge University Press, New York.

Michener, CD 1965 A classification of the bees of the Australian and South Pacific regions. Bulletin of the American Museum of Natural History 130: 1–362.

Pellmyr, O 2002 Pollination by animals. *in*: O Pellmyr, CM Herrera eds. Plant-animal interactions : An evolutionary approach. Blackwell Science, Oxford.

Stephens, PF 2004 Ericaceae. *in*: K Kubitzki ed. The families and genera of vascular plants. Vol. 6. Springer–Verlag, Berlin.

Thorp, RW 2000 The collection of pollen by bees. Plant Systematics and Evolution 222: 211–223.

Walsh, NG, TJ Entwisle 1996 Flora of Victoria. Volume 3. Royal Botanic Gardens, Melbourne.

Zborowski, P, R Storey 2003 A field guide to insects in Australia (second edition). Reed New Holland, Sydney.

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Appendix 1. Tasmanian Herbarium, Hobart (HO) voucher specimens

Sprengelia incarnata 2608, 5168, 5719, 5720, 5721, 5775, 5783, 5801, 5802, 8605, 51876, 72097, 79848, 89782, 94825, 106431, 119960, 400831, 405983, 407896; and

Sprengelia propinqua 2473, 5757, 5763, 5799, 5804, 58204, 76339, 77618, 89566, 119893, 120776, 120813, 121824, 123685, 315596, 401194, 402889, 403717, 404484, 406328.

Contrasting effects of fire severity on regeneration of the dominant woody species in two coastal plant communities at Wilsons Promontory, Victoria

J.W. Morgan[1] and C. Nield

Department of Botany, La Trobe University, Bundoora, VIC 3086, AUSTRALIA
[1]Author for correspondence: J.Morgan@latrobe.edu.au

***Abstract*:** Following wildfire in 2005 at Wilsons Promontory, Victoria, we asked how fire severity affected the post-fire regeneration of dominant woody species in two coastal plant communities. We documented the effects of fire severity (unburned, low, high) on stand mortality and seedling regeneration in shrublands dominated by the obligate seeder *Leptospermum laevigatum* (Myrtaceae) and woodlands dominated by the resprouting *Banksia integrifolia* var. *integrifolia* (Proteaceae). *Leptospermum laevigatum* is a range-expanding native species that has encroached into grassy *Banksia* woodland and hence, we were also interested whether fire severity affects post-fire succession in encroached and un-encroached stands. Fire severity impacted on all measures of post-fire recovery examined: stand mortality, seedling germination, seedling survival, seedling growth. High fire severity (complete canopy consumption) led to 100% mortality of both species. Despite variable responses at the stand level, mean *Leptospermum laevigatum* seedling establishment, growth and survival all increased with increasing fire severity in shrublands, thus ensuring shrublands are replaced. *Banksia integrifolia* recruitment, however, was minimal in all stands and not fire-cued. Increasing fire severity enabled *Leptospermum laevigatum* to recruit into woodland sites from where it was previously absent and this establishment, coupled with the loss of overstorey *Banksia* trees, may rapidly transform woodlands into shrublands. Hence, fire severity-induced population responses were observed and these imprints are likely to affect longer-term succession by reinforcing site occupancy of the encroaching *Leptospermum laevigatum* while simultaneously leading to the potential decline of *Banksia* woodlands.

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Introduction

Large fires do not burn homogeneously; most fires result in a mosaic of unburned and burned patches of varying size, shape and intensity (Turner *et al.* 1997, Chafer *et al.* 2004, Williams *et al.* 2006, Bradstock 2008). Plant population responses to fire are therefore likely to vary with fire severity, which should affect post-fire plant community recovery and subsequent succession (Morrison & Renwick 2002).

Fire severity, the impact of fire, is often assessed as the extent of canopy consumption and it is increasingly seen as an important determinant of how plant populations respond to fire (Chappell & Agee 1996, Pausas *et al.* 2003, Vivian *et al.* 2008). For example, adult plant mortality (Williams *et al.* 1999, Wright & Clarke 2007), seedling recruitment (Anderson & Romme 1991, Hodgkinson 1991, Moreno & Oechel 1991, Turner *et al.* 1999, Vivian *et al.* 2008), and ecosystem productivity (Christensen *et al.* 1989) have all been shown to vary with fire severity. Differences in fire severity may affect competitive interactions among plants in the post-fire environment (Ducey *et al.* 1996) and this may have important consequences for successional trajectories of plant communities (e.g. Ashton 1981, Ashton & Martin 1996, Turner *et al.* 2003), although these longer-term impacts have been less well-studied.

One particularly important interaction between fire and plant population response concerns range expanding species. Three classes of response to fire might be observed. Positive fire-range expansion relationships might be expected where fire promotes migration in obligate seeders that are constrained by competitors rather than climate (Vivian *et al.* 2008, Landhausser *et al.* 2010). Here, fire severity may play a key role by affecting the extent of post-fire competitive release that advantages expanding species (Johnstone & Chapin 2003). Neutral fire-range expansion responses, regardless of fire severity, would be expected where current species distributions are in equilibrium with climate. Negative fire-range expansion relationships might exist where fire-sensitive species (e.g. rainforest species) are excluded from burnt areas, with mortality increasing with fire frequency and/or severity (Fairfax *et al.* 2009).

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A common form of range expansion in southern Australia is the encroachment by indigenous obligate seeder shrubs into coastal grassland, heathland and woodland communities (Bennett 1994, Lunt 1998, Costello *et al.* 2000, Moxham *et al.* 2009, Lunt *et al.* 2010). This is primarily thought to occur because of the change in disturbance regimes that have characterized coastal ecosystems over the last five decades, particularly the absence of frequent fire and increasing disturbance associated with grazing. Shrub encroachment can exert strong negative ecosystem effects on native communities (Costello *et al.* 2000, Price & Morgan 2008) and hence, the re-introduction of fire is thought crucial for recovering the structure, if not composition, of these coastal systems (Molnar *et al.* 1989). There is little evidence, however, of whether fire severity is an important determinant of post-fire recovery of encroached stands, and whether these outcomes are likely to be positive, negative, or neutral with regards to dominant woody species responses. Such information is necessary if land managers are to re-institute fire in coastal landscapes with the aim of favoring native communities over encroaching shrubs.

In 2005, wildfire at Wilsons Promontory National Park, Victoria created a landscape with strong patchiness in burn severity across a range of coastal woodland communities that have been variously impacted by the native, range-expanding coastal shrub *Leptospermum laevigatum*. This fire provided a landscape template to ask questions about the role of fire severity on initial post-fire recovery of dominant species in encroached and un-encroached systems. In particular, we asked:

> (1) does fire severity impact regeneration of the structural dominants in (a) the extensive shrublands dominated by *Leptospermum laevigatum* compared to (b) the more restricted *Banksia integrifolia* grassy woodlands that are now imbedded in the shrublands?
>
> (2) can range-expanding species such as *Leptospermum* exploit differences in fire severity to expand into previously unoccupied plant communities such as *Banksia* woodland?

To answer these questions, we surveyed the stand dynamics and seedling regeneration patterns of the dominant woody species in *Leptospermum* shrublands and *Banksia* woodlands in areas unburned and compared this to the responses of vegetation affected by low and high fire severity.

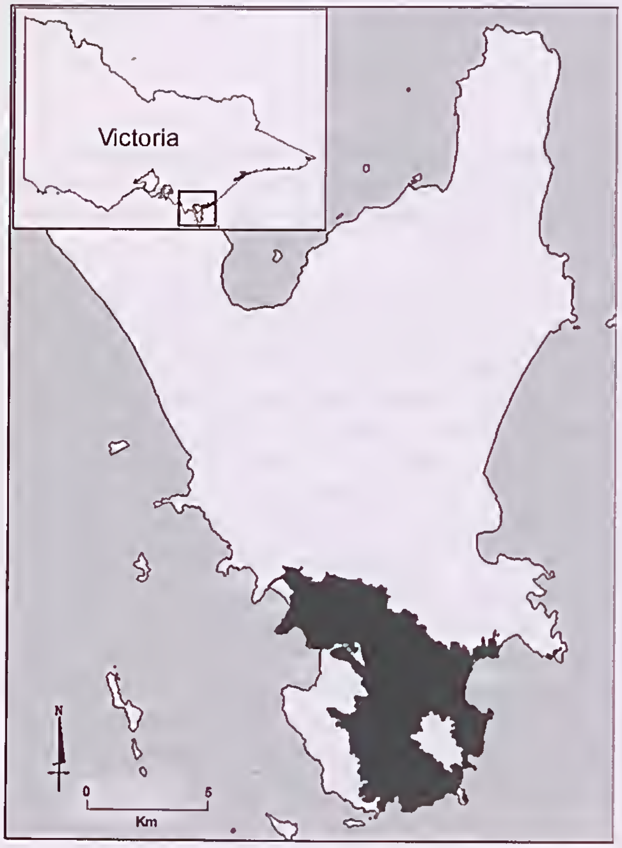

Fig. 1. Location of the 2005 wildfire (darkened area) in Wilsons Promontory National Park, Victoria.

Methods

Study area

Wilsons Promontory National Park forms the southernmost part of the Australian mainland. The climate is temperate and modified by maritime influences resulting in seasonally well-distributed temperatures and rainfall. Mean annual maximum temperature is 16.3 °C and mean annual minimum temperature is 11.2 °C. Mean annual rainfall is approximately 1060 mm, with maximum rainfall occurring in July (mean 121 mm) and minimum rainfall occurring in February (mean 46 mm) (Wilsons Promontory Lighthouse, Bureau of Meteorology, *unpublished data*).

In April 2005, approximately 13% (6143 ha) of the national park was burnt from a fire that originated at Tidal River (39° 00 S, 146° 25' E). The fire burnt from the west coast, across Mt Oberon to the east coast, and down to the southern coast in an area not burnt since 1951 (Fig. 1). No significant predictive models were found to explain variation in fire severity with vegetation type, slope, aspect or stand density (C.Nield *unpublished data*). Rather, local weather patterns seemed to play a more important role in determining local fire severity patterns within- and between-communities.

Study species and site selection

We focused on two coastal vegetation types that were common on the calcareous dunes in the Norman Bay and Oberon Bay area, and where fire severity mosaics were clearly obvious. Closed shrubland dominated by *Leptospermum laevigatum* and woodland dominated by *Banksia integrifolia* var. *integrifolia* were selected for comparative purposes to assess the effect of fire severity of stand mortality and seedling recruitment. We chose these vegetation types, in part because of management concerns about the extent and dynamic of these communities. *Leptospermum* is an expanding shrub species at Wilsons Promontory, having encroached from near-primary dune systems into hinterland vegetation over the last 50 yrs in the absence of fire (Burrell 1981, Bennett 1994, Ashton & van Gameren 2002). Here, it forms near mono-specific closed shrublands and threatens local diversity by competitive dominance (Parsons 1966, Ashton & van Gameren 2002). Re-introduction of fire is thought crucial as a management technique to reduce its occupancy and there is some indication of success where this has been applied (Molnar *et al.* 1989). By contrast, *Banksia integrifolia* var. *integrifolia* is in decline at Wilsons Promontory (Bennett & Attiwill 1996) and the extent of the grassy woodland community it dominates has been reduced, in part, due to *Leptospermum* encroachment in the absence of fire (Bennett 1994). Most remaining un-encroached *Banksia integrifolia* woodland occurs as 'islands' surrounded by a matrix of *Leptospermum* shrubland, as was the case in this study.

Leptospermum laevigatum (Myrtaceae) is an obligate seeding shrub to 5–10 m tall with annual seedfall. Successful seed regeneration is minimal or absent in undisturbed mature stands (Ashton & van Gameren 2002), but prolific after fire or soil disturbance (Burrell 1981). *Banksia integrifolia* var. *integrifolia* (Proteaceae) is a non-bradysporous tree to 25 m, shedding seeds annually as soon as the follicle matures, with germination in late-winter (Price & Morgan 2003). Hazard & Parsons (1977) suggest that whilst thick bark may provide protection against fire, survival depends on tree age and fire intensity.

Study sites were stratified first by (a) dominant species (*Banksia*, *Leptospermum*) and then by (b) fire severity (unburned, low, high). Sites were distributed across the range of topographic positions occupied by the species within the burnt area. Fire severity was determined in August 2005 (approx 3.5 months after fire) according to the criteria outlined in Table 1. We used visual estimates of fire severity rather than *post-hoc* measures such as twig diameter (e.g. as used by Williams *et al.* 2006) primarily because the vegetation was too tall to employ these quantitative measures. Sites were selected according to accessibility, fire severity patch size (minimum 50 x 50 m), fire severity patch homogeneity, and the absence of previous disturbance such as walking tracks or fire breaks. In total, eight *Leptospermum* stands (3 unburned, 2 low severity, 3 high severity) and nine *Banksia* stands (3 unburned, 3 low severity, 3 high severity) were chosen for study. *Banksia* woodlands had no *Leptospermum* present as mature plants but were surrounded by dense *Leptospermum* shrublands.

Table 1. Visual criteria used to assign shrubland and woodland stands at Wilsons Promontory, Victoria to fire severity classes.

Severity Class	Description
Unburnt	No sign of fire evident
Low	Surface burn only: ground layer mostly consumed, canopy remains largely intact or with light scorching at most, leaf litter present
High	Crown fire: ground layer completely consumed, canopy also completely consumed, leaf litter absent

Effects of fire severity on stand dynamics, seedling recruitment and growth

At each of the 17 stands, one plot was established within which all subsequent data were collected. Woodland plots were larger (30 x 20 m) than shrubland plots (20 x 20 m) to account for the more open structure of the former communities. All individuals of the target species were assessed for survival in each stand at 6 months after fire by assigning them as dead (no green shoots or canopy evident, bark lifted away from the trunk) or alive (obvious signs of resprouting from epicormic shoots, green canopy). For *Banksia*, girth over bark at breast height (GBBH) was measured for all individuals in each stand, while girth at 15 cm was measured for *Leptospermum* (because of low frequent branching) for a maximum of 30 plants per stand. Plants in unburned control plots were scored and measured in the same way.

Leptospermum seedling density was recorded in both shrubland and *Banksia* woodland stands in ten permanent 25 x 25 cm quadrats in the main plot. Within each quadrat, the total number of *Leptospermum* seedlings was counted at November 2005. Emergence did not occur until August/September 2005 but we waited until November before counting seedlings to ensure correct identification. *Leptospermum* seedling growth and survival were monitored over the first summer by tagging a maximum of 10 seedlings per quadrat in December 2005 and measuring their height at monthly intervals until March 2006. Seedling height was measured from the soil to the tip of the longest branchlet, and survival was determined by a visual estimation of leaf condition. Seedlings that died were assigned a probable cause of death: (a) desiccation (leaves intact but browned-off), (b) herbivory (seedling clearly nipped off), (c) unknown (seedling disappeared without a trace).

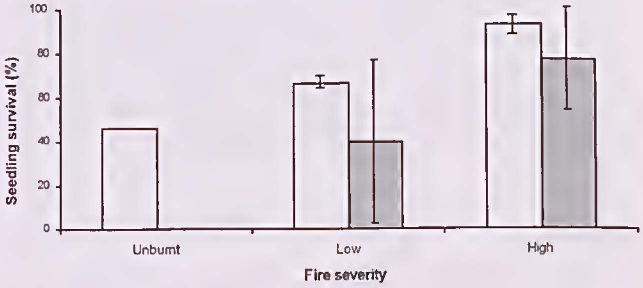

Fig. 2. Mean percent survival (± 95% CI) of tagged *Leptospermum laevigatum* seedlings at March 2006 in shrubland (□) and woodland (■) stands in relation to fire severity (unburnt, low, high) at Wilsons Promontory, Victoria. Note: there was no germination in unburnt *Banksia* woodland.

Table 2. Mean (± 95% CI) stand attributes (density, girth), and effect of fire severity of survival of *Leptospermum laevigatum* in shrublands and *Banksia integrifolia* in woodlands at Wilsons Promontory, Victoria. GBBH = girth over bark at breast height

Species	Attribute	Unit	Fire Severity		
			Unburnt	Low	High
Leptospermum	Stand density	Shrubs ha^{-1}	4967 ± 3757	5050 ± 6958	5167 ± 1059
	Basal girth	cm	44 ± 11	38 ± 24	25 ± 1
	Mortality	% of stand	7 ± 7	92 ± 17	100
Banksia	Stand density	Trees ha^{-1}	233 ± 105	339 ± 171	389 ± 202
	GBBH	cm	176 ± 20	127 ± 27	118 ± 53
	Mortality	% of stand	20 ± 8	88 ± 14	100

Table 3. Mean (± 95% CI) seedling density (per ha) of *Leptospermum laevigatum* and *Banksia integrifolia* var. *integrifolia* at November 2005 in response to fire severity and stand type at Wilsons Promontory, Victoria.

Stand type	Species	Fire severity		
		Unburnt	Low	High
Shrubland	*Leptospermum*	180,000 ± 350,000	770,000 ± 470,000	10,040,000 ± 12,330,000
Woodland	*Banksia*	78 ± 152	50 ± 98	89 ± 174
Woodland	*Leptospermum*	0	580,000 ± 610,000	2,010,000 ± 1,050,000

Banksia seedling density was so low that the whole 600 m^2 woodland plot was surveyed for recruitment. In December 2005, a 30 minute search of the plot area was undertaken at each stand and the total number of seedlings encountered was recorded. There were too few seedlings across the stands to follow survival and growth.

Data analysis

Due to large within-stand variation in most parameters and low stand replication, we assessed differences in mean stand density, mean stand girth, effects of fire severity on mean stand seedling density (at November 2005), and mean percent seedling survival (of tagged individuals at March 2006) as the percentage change between fire severity class stands and by examining overlap of 95% confidence intervals (Cumming & Finch 2005). Hence, for a comparison of two independent means, $p<0.05$ when the overlap of the 95% CIs is no more than about half the average margin of error, i.e., when proportion overlap is about 0.50 or less; $p < 0.01$ when the two CIs do not overlap (Cumming & Finch 2005). For *Leptospermum* in shrubland and *Banksia* woodland, monthly seedling height (mean height of tagged seedlings per stand) was compared across fire severity classes using repeated measures ANOVA, comparing the effect of severity and time, and the interaction between severity and time on seedling growth.

Results

Stand structure and mortality

Leptospermum stand density was high (mean ≈5000 plants hectare^{-1}) and variable, but not significantly different across fire severity classes (Table 2). Fire resulted in very high mortality of *Leptospermum*; all plants in the high fire severity stands were dead after fire, while a few plants in the low severity stand survived the fire event (Table 2). Background levels of mortality in unburned sites, by comparison, were low (Table 2).

Banksia trees were large (mean >115 cm GBBH) and occurred at similar densities in all fire severity stands (Table 2). Mean tree mortality was high at both low and high fire severity (88% and 100% respectively, Table 2). A considerable proportion of the trees were dead in unburned stands (mean 20%, Table 2).

Seedling recruitment

Mean *Leptospermum* seedling density was highly variable across stands (Table 3) but fire severity had a clear impact on seedling establishment with a ≈1200% increase in mean seedling density in the high fire severity stands relative to low fire severity stands (Table 3).

Banksia seedlings were patchily distributed in all woodland stands, with no seedlings in six of the nine stands (two in each fire severity class) and there was no evidence that fire positively affected seedling regeneration (Table 3).

Leptospermum seedlings were observed after fire in previously unoccupied *Banksia* woodland stands. Fire severity had a clear effect on their establishment (Table 3). No seedlings were observed in unburned *Banksia* stands, but mean seedling density increased significantly (by 247%) with increasing fire severity (Table 3).

Seedling survival

Percent survival of tagged *Leptospermum* seedlings in shrublands at March 2006 was high and increased significantly with fire severity (i.e. increased by an average of 39% in high versus low fire severity stands; Fig. 2). The cause of death of seedlings differed according to fire severity. In unburned and high fire severity stands, mortality appeared to be due to desiccation, whereas in the low fire severity stands, herbivory was the major cause of death (Table 4).

Leptospermum seedling survival in *Banksia* woodland was not significantly different between low and high fire severity stands due to high stand variation, and was lower and more variable than in shrubland stands (Fig. 2). The cause of seedling mortality differed according to fire severity in a way that was similar to that seen in the shrublands (Table 4). In the low fire severity stands, herbivory was the most obvious cause of mortality whereas seedlings in the high fire severity stands died mainly due to the effects of desiccation (Table 4).

Table 4. Potential cause of mortality of Leptospermum laevigatum seedlings in shrublands and woodlands at Wilsons Promontory, Victoria in relation to fire severity. Note: there was no germination of Leptospermum in unburnt Banksia woodland.

Stand	**Fire severity class**	**Cause of mortality** (as a % of those seedlings that died)		
		Herbivory	Desiccation	Unknown
Shrubland	Unburnt	7	79	14
	Low	78	11	11
	High	0	88	12
Woodland	Low	57	29	14
	High	9	88	3

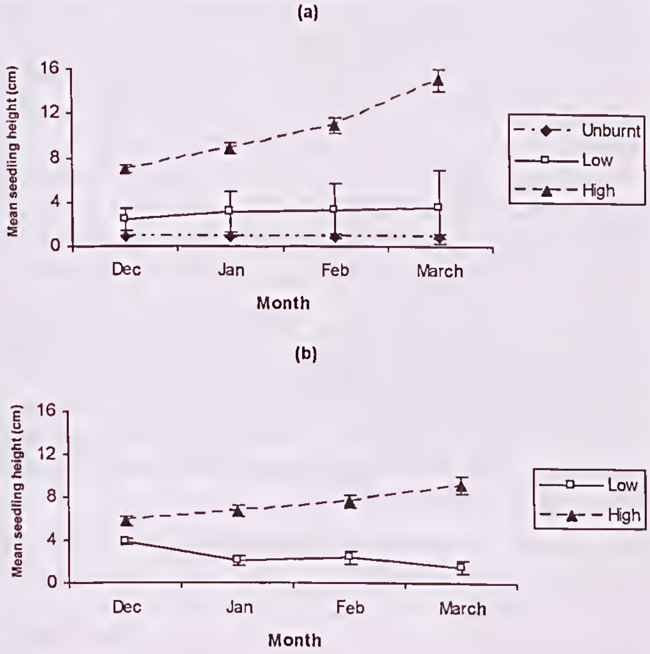

Fig. 3. Mean (± 1 SE) *Leptospermum laevigatum* height of seedlings in (a) shrubland and (b) woodland with respect to fire severity (unburnt, low, high) and month (7–11 months post-fire). Note: there was no germination in unburnt *Banksia* woodland.

Seedling growth

The mean height of *Leptospermum* seedlings in shrublands increased significantly with fire severity (F = 39.88, P< 0.001) and remained significant over the sampling period (F= 39.93, P<0.001) (Fig. 3). The growth of *Leptospermum* seedlings was also significantly affected by the interaction between fire severity and time (F= 15.52, P<0.001), with seedlings in the high severity sites outperforming others, particularly later in the season. Seedling that did emerge in the unburned sites showed no evidence of net growth over the sampling period (Fig. 3).

The mean height of *Leptospermum* seedlings in *Banksia* woodland stands was not significantly affected by fire severity (P = 0.103) or time (P = 0.85), but was significantly affected by a severity and time interaction (F= 2.35, P<0.05, Fig. 3). Hence, while fire severity did not significantly affect mean growth, the treatments did differ over time. The high fire severity stands were the only sites to show a net increase in seedling height over the four month sampling period (Fig. 3).

Discussion

Fire severity is an under-studied aspect of the response of natural vegetation to wildfire but appears to play a crucial role in post-fire recovery in many ecosystems (e.g. Turner *et al.* 1999, Ooi *et al.* 2006, Vivian *et al.* 2008). Post-fire successional processes are likely to be affected by fire severity because of its impact on stand mortality and seedling regeneration (Moreno & Oechel 1991, Turner *et al.* 1999). It is clear that at Wilsons Promontory, differences in fire severity have led to changes in the initial recovery in shrublands and woodlands by affecting adult mortality and recruitment dynamics of the dominant species. This may have set the template for long-lasting structural change in these coastal communities.

Fire severity played out in three obvious ways. In both shrublands and woodlands, increasing fire severity led to increased stand mortality, with 100% mortality observed in both shrublands and woodlands at high fire severity where canopies were consumed by fire. For *Leptospermum laevigatum*, an obligate seeder, this was not unexpected. Even where fire only scorched the canopy rather than consumed it, there was sufficient heating to cause near total adult mortality. However, for *Banksia integrifolia* var. *integrifolia*, a tree thought to be capable of resprouting after fire, this was more surprising. The literature suggests that *Banksia integrifolia* var. *integrifolia* resprouts by epicormic shoots after fire, although Hazard & Parsons (1977) note that this may depend on fire severity. We now have sound evidence that canopy-consuming fires can cause complete stand mortality in this species. Low fire severity (i.e. ground fire) also led to high stand mortality (i.e. mean 88%) and this may be because many trees were old (as evidenced by mean stand GBBH >125 cm) and showing signs of senescence (Bennett & Attiwill 1996).

Secondly, fire severity significantly affected seedling regeneration of *Leptospermum laevigatum* in shrublands, but not *Banksia integrifolia* in woodlands. The post-fire recruitment of *Leptospermum laevigatum* has been well-documented (Burrell 1981, Bennett 1994, Ashton & van Gameren 2002), although the effects of fire severity have not been previously observed. Germination under the unburnt shrubland canopy does occur (Ashton & van Gameren 2002), and seedlings grew very slowly, reached minimal height, had high mortality, and are unlikely to contribute to the population. With increasing fire severity, seedling regeneration, despite high variability at the stand level, increased dramatically. The availability of bare ground and high light conditions (Burrell 1981), as well as fire-induced mass seedfall from woody capsules that can survive high temperatures for short durations (Judd 1993), are likely to have maximised seed availability, germination and survival in high fire severity stands. In low fire severity stands, by comparison, bare ground is likely lower (due to incomplete litter consumption), canopy interception of light higher (due to the scorching rather than consumption of foliage), and initial seed release may have been lower; this may explain the lower levels of germination observed there.

For the non-bradysporous *Banksia integrifolia* var. *integrifolia*, seedling regeneration can occur in the inter-fire period (Price & Morgan 2003, Gent & Morgan 2007). While fire could aid seedling germination and initial survival by the removal of competitors and the increase in light availability, it has been suggested that in harsh environments like coastal dunes, facilitation by the unburnt ground layer vegetation may play an important role in *Banksia* establishment (Price & Morgan 2003). Hence, it was perhaps not unexpected that post-fire seedling densities were low and not promoted by fire *per se*. Additionally, the poor health of the adult population may have contributed to low seed rain post-fire (Price & Morgan 2003) and hence, restricted opportunities for seedling germination in the post-fire environment.

Thirdly, increasing fire severity positively affected the growth of *Leptospermum laevigatum* seedlings over the first growing season in shrublands. Inter- and intra-specific overstorey competition has been shown to suppress *Leptospermum* seedling regeneration through competition for light and soil moisture (Ashton & van Gameren 2002). High fire severity had the most impact on canopy and branch reduction in shrublands, and this likely eliminated competition in the post-fire environment to a greater extent than occurs following low fire severity, which left a scorched (but intact) canopy which continued to intercept light. Higher post-fire soil fertility with high fire severity has been observed elsewhere (Pausas *et al.* 2003) and this may also contribute to faster growth in *Leptospermum* seedlings (Burrell 1981). Vivian *et al.* (2008) found similar positive effects of fire severity on initial seedling growth for the obligate seeding tree *Eucalyptus delegatensis*, hinting that fire severity plays a critical role for establishment of those species strongly constrained by competitive processes rather than climate. In *Banksia* woodland, however, fire severity had less impact on growth of *Leptospermum* seedlings. While seedlings initially grew taller in high fire severity stands, this growth was not maintained, perhaps because herbaceous competitors in the understorey were fast to recover, regardless of fire severity.

The increase in mean density, survival and growth of *Leptospermum* seedlings with increasing fire severity was clear, yet this trend differs from that observed for shrubs in semi-arid woodland (Hodgkinson 1991, Pausas *et al.* 2003) and trees in northern hemisphere forests (Anderson & Romme 1991, Chappell & Agee 1996, Turner *et al.* 1999). In these systems, highest recruitment occurs after low to moderate severity fire, perhaps because of the consumption of canopy seed in high severity fires. This disparity may be due to differences in seed properties in the different ecosystems, or it may just reflect the subjective nature of the fire severity classifications used. In a comparative sense, fire severity in shrubland at Wilsons Promontory may have been at the lower end of the fire severity continuum relative to forest or woodland canopy fires, allowing high proportions of *Leptospermum laevigatum* seed to survive even after 'high severity' fire. However, in a relative sense, the high fire severity stands we identified in shrublands at Wilsons Promontory experienced fire orders of magnitude higher than the low severity fires, and it is suspected to be at the upper end of the fire intensities that would occur in these communities. Hence, the general responses to fire severity in coastal shrublands would still appear to differ from those observed elsewhere.

While many of the general effects of fire severity we observed on mortality and recruitment are well known, we also found that fire severity impacted upon post-fire recovery in two less obvious ways. Fire severity had an indirect impact on the cause of *Leptospermum* seedling mortality in both shrublands and woodlands. After low severity fire, slugs, caterpillars and other insects colonised the post-fire regrowth in large numbers and were seen actively feeding on seedlings (author. *pers. obsv.*). By contrast, in high fire severity shrubland stands, seedlings died due to desiccation over the summer months, presumably because there was little shading from regrowing vegetation. Surprisingly, mortality of *Leptospermum* in the high severity sites was low, despite seedling density being highest there, indicating that mortality was not density-dependent as is often observed (Hodgkinson 1991, Harms *et al.* 2000). Rather, in the open, well-lit, sandy soils, seedlings that were not well protected by near neighbours were most likely to be affected by heat and drought stress.

Fire severity also provided differential opportunities for *Leptospermum* to establish in previously un-encroached *Banksia* woodland stands. No *Leptospermum* seedlings were observed in unburnt woodland, presumably because of high vegetation cover and a lack of bare ground (i.e. the absence of regeneration niches) (Burrell 1981, Bennett 1994). By contrast, fire provided opportunities for *Leptospermum* seedling germination in woodland by removing canopy and groundlayer competitors, as well as a temporary increase in soil nutrients (Burrell 1981). Enhanced seed supply was provided by 'spillover' dispersal from adjoining shrubland stands that were burned (i.e. the mass ratio effect; Grime 1998). Seedling germination, establishment and growth were all higher at high fire severity where bare ground was higher and it is possible that high fire severity has led to the establishment of *Leptospermum* founder populations that may lead to a vegetation state change in *Banksia* woodland.

Predictions for long-term vegetation development from initial fire responses

Variation in fire severity has the ability to initiate changes in stand composition and structure, and may generate a number of alternative successional pathways in plant communities (Turner *et al.* 1997, 1999, 2003). The high *Leptospermum. laevigatum* seedling density promoted by high severity fire will most likely result in the complete re-occupation of the shrubland sites by a dense *Leptospermum laevigatum* stand. In the years following fire, as the canopy closes over and litter levels build up, small-scale species coexistence is predicted to decline (Costello *et al.* 2000, Price & Morgan 2008). By contrast, in shrubland exposed to low fire severity, seedling recruitment was lower and may result in more open, mixed stands with lower densities of *Leptospermum laevigatum* and a higher number of coexisting species. If fire was re-introduced into these sites at high frequency, before *Leptospermum laevigatum* seedlings attain reproductive age (≤ 5 years) (Bennett 1994), it may be possible to reduce or even remove *Leptospermum laevigatum*, and push the system away from its current state.

The widespread senescence of *Banksia integrifolia* stands, the high levels of fire-induced tree mortality, low and patchy seedling recruitment after fire, as well as high density of *Leptospermum laevigatum* seedlings in woodlands after fire, all point towards a complete state change of burnt *Banksia* woodlands at Wilsons Promontory. The encroachment of woodland by *Leptospermum laevigatum* in the absence of fire has been of ongoing concern to park managers aiming to maintain biodiversity and increase habitat heterogeneity; the 2005 fire seems likely to have only exacerbated that concern. The poor pre-fire health and widespread senescence of *Banksia integrifolia* var. *integrifolia* populations may have increased their sensitivity to fire *per se* and it is hard to see how re-implementing fire (as a regime) will restore these communities to their former state. The consequences of the loss of this 'foundation species' (*sensu* Ellison *et al.* 2005) are likely to be felt in the decades to come.

Conclusion

The establishment, growth and survival of *Leptospermum laevigatum* seedlings in shrubland and woodland were clearly promoted by fire. The post-fire environment of high light, bare soil and the lack of canopy and groundcover competition likely provided the temporary opportunity necessary for abundant recruitment of this encroaching species. Hence, one-off fires of any severity are unlikely to eliminate this species from plant communities into which it has substantially encroached. Rather, high fire severity in shrublands is likely to promote or reinforce the dominance of *Leptospermum*. By contrast, *Banksia integrifolia* var. *integrifolia* mortality was high, seedling recruitment was minimal and not promoted by fire, and it is likely that stand-level changes in dominance may occur in woodlands as a consequence of both fire and subsequent shrub encroachment, with subsequent important effects on habitat heterogeneity and ecosystem function. Restoring this community is likely to be challenging, and the use of fire in this process is likely to have variable outcomes depending on tree age, health and landscape context.

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References

Anderson, J. & Romme, W. (1991) Initial floristics in lodgepole pine (*Pinus contorta*) forests following the 1988 Yellowstone fires. *International Journal of Wildland Fire* 1: 119–124.

Ashton, D.H. (1981) The ecology of the boundary between *Eucalyptus regnans* F.Muell. and *E. obliqua* L'Herit. in Victoria. *Proceedings of the Ecological Society of Australia* 11: 75–94.

Ashton, D.H. & Martin, D.G. (1996) Regeneration in a pole-stage forest of *Eucalyptus regnans* subjected to different fire intensities in 1992. *Australian Journal of Botany* 44: 393–410.

Ashton, D. & van Gameren, M. (2002) Vegetation of sand dunes at Wilsons Promontory, Victoria. *Proceedings of the Royal Society of Victoria* 114: 43–58.

Bennett, L. (1994) The expansion of *Leptospermum laevigatum* on the Yanakie Isthmus, Wilsons Promontory, under changes in the burning and grazing regimes. *Australian Journal of Botany* 42: 555–564.

Bennett, L. & Attiwill, P. (1996) The nutritional status of healthy and declining stands of *Banksia integrifolia* on the Yanakie Isthmus, Victoria. *Australian Journal of Botany* 45: 15–30.

Bradstock, R.A. (2008) Effects of large fires on biodiversity in south-eastern Australia: disaster or template for biodiversity? *International Journal of Wildland Fire* 17: 809–822.

Burrell, J. (1981) Invasion of coastal heaths of Victoria by *Leptospermum laevigatum* (J. Gaertn) F. Muell. *Australian Journal of Botany* 29: 747–64.

Chafer, C., Noonan, M. & MacNaught, E. (2004) The post-fire measurement of fire severity and intensity in the Christmas 2001 Sydney wildfires. *International Journal of Wildland Fire* 13: 227–240.

Chappell, C. & Agee, J. (1996) Fire severity and tree seedling establishment in *Abies magnifica* forests, Southern Cascades, Oregon. *Ecological Applications* 6: 628–640.

Christensen, N., Agee, J., Brussard, P., Hughes, J., Knight, D., Minshall, G., Peek, J., Pyne, S., Swanson, F., Thomas, J., Wells, S., Williams, S. & Wright, H. (1989) Interpreting the Yellowstone fires of 1988. Ecosystem responses and management implications. *Bioscience* 39: 678–685.

Costello, D.A., Lunt, I.D. & Williams, J.E. (2000) Effects of invasion by the indigenous shrub *Acacia sophorae* on plant composition of coastal grasslands in south-eastern Australia. *Biological Conservation* 96: 113–121.

Cumming, G. & Finch, S. (2005) Inference by eye – confidence intervals and how to read pictures of data. *American Psychologist* 60: 170–180.

Ducey, M., Moser, W. & Ashton, P. (1996) Effect of fire intensity on understorey composition and diversity in a *Kalmia*–dominanted oak forest, New England, USA. *Vegetatio* 123: 81–90.

Ellison, A., Bank, M., Clinton, B., Colburn, E., Elliott, K., Ford, C., Foster, D., Kloeppel, B., Knoepp, J., Lovett, G., Mohan, J., Orwig, D., Rodenhouse, N., Sobczak, W., Stinson, A., Stone, J., Swan, C., Thompson, J., Von Holle, B. & Webster, J. (2005) Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and Environment* 3: 479–486.

Fairfax, R., Fensham, R., Butler, D., Quinn, K., Sigley, B. & Holman, J. (2009) Effects of multiple fires on tree invasion in montane grasslands. *Landscape Ecology* 24: 1363–1373.

Gent, M.L. & Morgan, J.W. (2007) Changes in the stand structure (1975–2000) of coastal *Banksia* forest in the long absence of fire. *Austral Ecology* 32: 239–244.

Grime, J.P. (1998) Benefits of plant diversity to ecosystems: immediate, filter and founder effects. *Journal of Ecology* 86: 902–910.

Harms, K., Wright, S., Calderon, O., Hernandez, A. & Herre, E. (2000) Pervasive density-dependent recruitment enhances seedling diversity in a tropical forest. *Nature* 404: 494–495.

Hazard, J. & Parsons, R.F. (1977) Size-class analysis of coastal scrub and woodland, Western Port, southern Australia. *Australian Journal of Ecology* **2:** 187–97.

Hodgkinson, K. (1991) Shrub recruitment response to intensity and season of fire in a semi-arid woodland. *Journal of Applied Ecology* 28: 60–70.

Johnstone, J.F. & Chapin, F.S. (2003) Non-equilibrium succession dynamics indicate continued northern migration of lodgepole pine. *Global Change Biology* 9: 1401–1409.

Judd, T. (1993) Seed survival in small myrtaceous capsules subjected to experimental heating. *Oecologia* 93: 576–581.

Landhausser, S.M., Deshaies, D. & Lieffers, V.J. (2010) Disturbance facilitates rapid range expansion of aspen into higher elevations of the Rocky Mountains under a warming climate. *Journal of Biogeography* 37: 68–76.

Lunt, I.D. (1998) *Allocasuarina* (Casuarinaceae) invasion of an unburnt coastal woodland at Ocean Grove, Victoria: structural changes 1971–1996. *Australian Journal of Botany* 46: 649–656.

Lunt, I.D., Winsemius, L.M., McDonald, S.P., Morgan, J.W. & Dehaan, R.L. (2010) How widespread is woody plant encroachment in temperate Australia? Changes in woody vegetation cover in lowland woodland and coastal ecosystems in Victoria from 1989 to 2005. *Journal of Biogeography* 37: 722–732.

Molnar, C., Fletcher, D. & Parsons, R. (1989) Relationships between heath and *Leptospermum laevigatum* scrub at Sandringham, Victoria Australia. *Royal Society of Victoria Proceedings* 101: 77–88.

Moreno, J. & Oechel, W. (1991) Fire intensity effects on germination of shrubs and herbs in southern California chaparral. *Ecology* 72: 1993–2004.

Morrison, D. & Renwick, J. (2002) Effects of variation in fire intensity on regeneration of co-occurring species of small trees in the Sydney region. *Australian Journal of Botany* 48: 71–79.

Moxham, C., Sinclair, S., Walker, G. & Douglas, I. (2009) The vegetation of the Nepean Peninsula, Victoria – an historical perspective. *Cunninghamia* 11: 27–47.

Ooi, M.K.J., Whelan, R.J. & Auld, T.D. (2006) Persistence of obligate-seeding species at the population scale: effects of fire intensity, fire patchiness and long fire-free intervals. *International Journal of Wildland Fire* 15: 261–269.

Parsons, R.F. (1966) The soils and vegetation at Tidal River, Wilson's Promontory. *Proceedings of the Royal Society of Victoria* 79: 319–54.

Pausas, J.G., Ouadah, N., Ferran, A., Gimeno, T. & Vallejo, R. (2003) Fire severity and seedling establishment in *Pinus halepensis* woodlands, eastern Iberian Peninsula. *Plant Ecology* 169: 205–213.

Price, J.N. & Morgan, J.W. (2003) Mechanisms controlling establishment of the non-bradysporous *Banksia integrifolia* (Coast Banksia) in an unburnt coastal woodland. *Austral Ecology* 28: 82–92.

Price, J.N. & Morgan, J.W. (2008) Woody plant encroachment reduces species richness of herb-rich woodlands in southern Australia. *Austral Ecology* 33: 278–289.

Turner, M., Hargrove, W., Gardner, R. & Romme, W. (1994) Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. *Journal of Vegetation Science* 5: 731–742.

Turner, M., Romme, W. & Gardner, R. (1999) Prefire heterogeneity, fire severity, and early postfire plant reestablishment in subalpine forests of Yellowstone National Park, Wyoming. *International Journal of Wildland Fire* 9: 21–36.

Turner, M., Romme, W., Gardner, R. & Hargrove, W. (1997) Effects of fire size and pattern on early succession in Yellowstone National Park. *Ecological Monographs* 67: 411–433.

Turner, M., Romme, W. & Tinker, D. (2003) Surprises and lessons from the 1988 Yellowstone fires. *Frontiers in Ecology and Environment* 1: 351–358.

Vivian, L.M., Cary, G.J., Bradstock, R.A. & Gill, A.M. (2008) Influence of fire severity on the regeneration, recruitment and distribution of eucalypts in the Cotter River Catchment, Australian Capital Territory. *Austral Ecology* 33: 55–67.

Williams, R., Cook, G., Gill, A. & Moore, P. (1999) Fire regime, fire intensity and tree survival in a tropical savanna in northern Australia. *Australian Journal of Ecology* 24: 50–59.

Willams, R.J., Wahren, C-H., Bradstock, R.A. & Muller, W.J. (2006) Does alpine grazing reduce blazing? A landscape test of a widely-held hypothesis. *Austral Ecology* 31: 925–936.

Wright, B.R. & Clarke, P.J. (2007) Resprouting responses of *Acacia* shrubs in the western desert of Australia – fire severity, interval and season influence survival. *International Journal of Wildland Fire* 16: 317–323.

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Native plants of Sydney Harbour National Park: historical records and species lists, and their value for conservation monitoring

Doug Benson

National Herbarium of New South Wales, Royal Botanic Gardens, Mrs Macquaries Rd, Sydney 2000 AUSTRALIA
doug.benson@rbgsyd.nsw.gov.au

Abstract: Sydney Harbour National Park (lat 33° 53'S; long 151° 13'E), protects significant vegetation on the harbour foreshores close to Sydney City CBD; its floristic abundance and landscape beauty has been acknowledged since the writings of the First Fleet in 1788. Surprisingly, although historical plant collections were made as early as1802, and localised surveys have listed species for parts of the Park since the 1960s, a detailed survey of the flora of whole Park is still needed.

This paper provides the first definitive list of the c.400 native flora species for Sydney Harbour National Park (total area 390 ha) showing occurrence on the seven terrestrial sub-regions or precincts (North Head, South Head, Dobroyd Head, Middle Head, Chowder Head, Bradleys Head and Nielsen Park). The list is based on historical species lists, records from the NSW Office of Environment and Heritage (formerly Dept of Environment, Climate Change and Water) Atlas, National Herbarium of New South Wales specimen details, and some additional fieldwork. 131 species have only been recorded from a single precinct site and many are not substantiated with a recent herbarium specimen (though there are historical specimens from the general area for many). Species reported in the sources but for which no current or historic specimen exists are listed separately as being of questionable/non-local status.

About 85% of the 400 species are recorded as being from North Head, the largest precinct, though the smallest Chowder Head does not have the fewest species. As well as size, differences indicate the different flora of inner harbour sites; inner harbour Bradleys Head and Nielsen Park include 24% of the single record species. Rare and threatened species, and regionally important species are discussed in relation to current threats which include weed invasion, fire frequency, *Phytophthora*, Black rats and tourism pressures.

Given the threats to the flora it is an appropriate time to take stock of the flora as a basic structural component of the biodiversity. What is now needed is a systematic survey (with quadrat-based methodology) to provide baseline data against which to compare state of Park trends with future resurvey. In the absence of such a survey this list at least will provide a reasonably definitive list of the species occurring in the Park regions at the beginning of the 21st Century. If only we had done this at the beginning of the 20th Century!

Key words: Sydney Harbour, native plant species lists, First Fleet observations, conservation monitoring

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Introduction

Sydney Harbour National Park encompasses much of the surviving natural vegetation on the foreshores of Sydney Harbour, on the doorstep of the Sydney City CBD, and provides the backdrop to many harbour activities. Because its precincts are located close to the homes and workplaces of a large and influential urban population, the Park has a significant role in demonstrating the value and importance of conservation management as well as protecting the diversity of a sample of Sydney's natural landscape. The contribution of the wildlife, particularly the birds, to the harbour environment is widely recognised, but the green backdrop, the vegetation and flora, is equally important. Indeed 21st Century views of the natural harbour foreshores can provide a direct connection with the first 18th Century European visitors. … *It suggests to the Imagination Ideas of luxuriant Vegetation and rural Scenery, consisting of gentle risings and & Depressions, beautifully clothed with variety of Verdures of evergreens, forming dense Thickets, & lofty Trees appearing above these again, and now & then a pleasant checquered Glade opens to your View.* wrote George Worgan, surgeon on the First Fleet flagship *Sirius* on entering the harbour in 1788 (Worgan 1978). A trip on a Manly Ferry can provide similar impressions today.

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Scientific exploration of the Harbour vegetation has been relatively slow. During the 19th Century visiting botanists made plant collections from the general Harbour area as it was easily accessible from Sydney. The earliest specimens from Sydney Harbour National Park are probably amongst a number broadly labelled *Sydney to South Head* collected by Robert Brown in 1802. The opening of the National Herbarium of NSW in the Sydney (now Royal) Botanic Gardens in 1901 began a period of intensive collecting by its employees including Director, Joseph Maiden, and botanical assistants Ernest Betche, John Boorman and Arthur Hamilton. During the period up to World War I plant collections were made from many Harbour localities including Mosman, Manly and Rose Bay.

In the 1960s increasing public interest in protecting bushland led to the creation of Sydney Harbour National Park (under the newly formed National Parks & Wildlife Service) from existing bushland parks (Ashton Park, Bradleys Head, Nielsen Park) with gradual incorporation of former military lands at Middle Head, North Head and South Head, as well as a number of Harbour islands. There was also public interest in developing scientific bushland management techniques. Major bushland management issues from that time were the recognition of invasion of exotic weeds (generally of garden origin) as a threat, and the impact of fire intensity, particularly low intensity control burning which failed to encourage good native vegetation regrowth while allowing prolific regrowth and seedlings of weed species. Both these issues were at the core of work done by Eileen and Joan Bradley at Bradleys and Chowder Heads (Bradley & Bradley 1967, Bradley 1972) and led to influential bushland regeneration techniques being developed (e.g. Buchanan 2009). Eileen Bradley (1972) also reported the first documented occurrence of serious overall deterioration (die-back) of eucalypts particularly on the lower eastern side of Bradleys Head (over the period 1965–1972). She also reported that the pathogen *Phytophthora cinnamomi* had been isolated from soil there, and proved capable of killing *Angophora* trees grown in pots. Tree die-back was subsequently reported to be caused by airborne pollutants from ocean sewer outfalls (Anderson et al 1981) (ocean outfalls were moved further offshore to reduce their impacts in the 1990s) but Daniel et al (2006) subsequently confirmed that *Phytophthora* was at least partially involved in the dieback of plant species at Middle Head and North Head.

On North Head vegetation research includes Clemens & Franklin's (1980) study of changes around the Fairfax walk, and Horton and Bensons' (1986) extensive site-based vegetation survey involving a grid of 180 20x20 m sites across the National Parks and Wildlife Service part of North Head. Further surveys of areas beyond the National Park were undertaken by Skelton et al (2003) when the Sydney Harbour Federation Trust took over the central area of North Head from the Army School of Artillery. Conservation measures to protect its important vegetation, including monitoring recovery of endangered Eastern Suburbs Banksia Scrub after burning, were implemented by the new management. Faunal research has concentrated on the endangered populations of Little Penguins (NSW National Parks & Wildlife Service 2000a) and Long-nosed Bandicoots (NSW National Parks & Wildlife Service 2000b), and threats posed by foxes, rabbits and Black rats (Peter Banks pers. comm.). At Nielsen Park, apart from Dorothy Holland's (1980) vegetation survey, research work has been concentrated on ensuring the survival of the Endangered shrub *Allocasuarina portuensis* whose total natural distribution is confined to this precinct of the Park.

However a review of vegetation survey of the Park to provide background data for the 2010–2020 Plan of Management

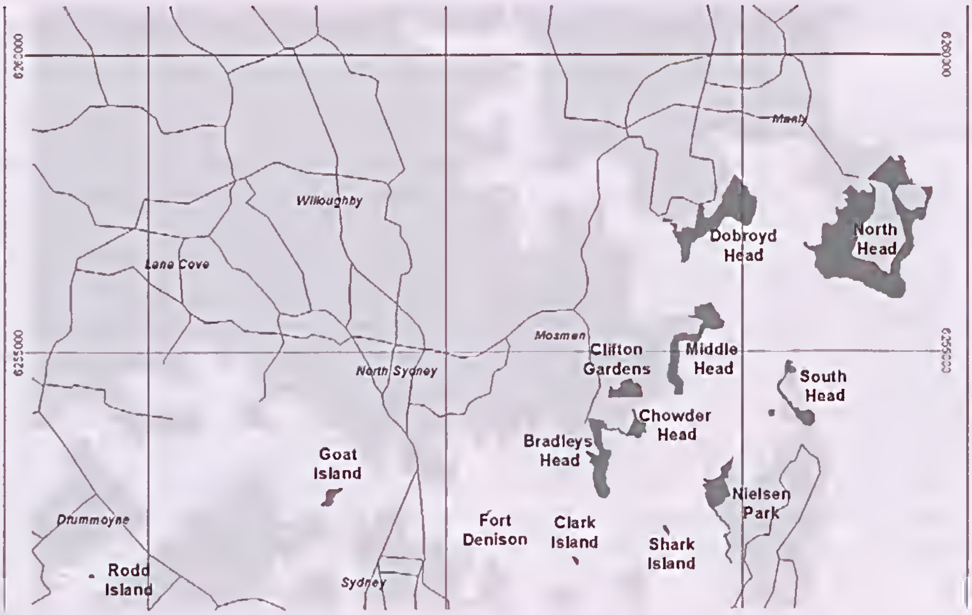

Fig. 1. Location of Sydney Harbour National Park showing separate headland precincts

Table 1 Islands of Sydney Harbour National Park, and some others, with notes and references to native vegetation (see Clark & Clark (2000) for descriptions).

Sydney Harbour NP (area in ha)	History	Notes on vegetation/remnant native species
Shark 1 ha in area	Cleared and developed as picnic grounds	A few foreshore native species
Clark 1 ha	Picnic ground, naval storage	Native vegetation, regeneration since 1970
Goat 6.5 ha	Powder magazine, quarries and shipyards, 19th –20th centuries	Mainly cleared but remnants of native vegetation and considerable plantings (Pratten & Benson 1985)
Fort Denison 0.2 ha	Cleared and developed by 1850s	None
Rodd 0.5 ha	Pleasure grounds	A few foreshore native species
Other islands		
Garden Island orig. about 550 m long but now joined to mainland	Naval headquarters, 19th–20th centuries	A few remnant species surviving around sandstone cliffs. Rodd & Benson (1977) listed 24 native species persisting in 1977.
Cockatoo orig 13 ha in area, now 18 ha	Convict gaol in 19th Century, completely altered for shipbuilding in 20th	A few recolonising species on clifflines eg *Psilotum nudum*; much recent replanting
Berry Island	Bushland park, joined to mainland	Extensive native woodland
Spectacle Island <1 ha	Naval training site	A tiny rocky sandstone knoll with a few native species including *Acacia suaveolens* still remained in 2000 (DHB pers. obs.)

revision showed that although there have been surveys of parts of the park, particularly North Head, no detailed survey of the flora of whole area at a single time has been carried out. The aim of this current work has been to develop a census, listing all species that are native to the Park area (i.e. are likely to have been present at the time of European settlement of Sydney in 1788), as well as some idea of the current flora distribution across the precincts. Since 1788 some species may have disappeared, while others may have moved in. Given the high profile of the Park and the increasing threats to its flora, this is an appropriate time to take stock of current information sources and their adequacy for floristic biodiversity, and to provide guidelines for future research.

Sydney Harbour National Park description

Sydney Harbour National Park (Figure 1) (lat 33° 53'S; long 151° 13'E) occupies a significant part of the foreshores of Sydney Harbour (historically known as Port Jackson). The total land area of the Park (390 ha) is divided between a number of separate foreshore subregions or precincts, mainly Hawkesbury Sandstone headlands: North Head, Dobroyd Head, Bradleys Head, Middle Head (including Clifton Gardens), Chowder Head, South Head and Nielsen Park (Fig. 1), as well as a number of Harbour islands (total island area about 10 ha). All precincts include substantial areas of natural vegetation but also cleared areas with mown lawns, as well as buildings and old fortifications from the former military occupation. While all precincts have substantial natural foreshore margins, all adjoin some urban residential housing areas. All of the islands, except Clarke, have been essentially cleared of terrestrial native vegetation (Clark & Clark 2000) (Table 1).

Geomorphology and soils are important determinants of vegetation. While Sydney Harbour National Park is mainly of sandstone geology there are important local variations with a capping of Pleistocene sand on North Head, and increased shale influences up the harbour. Annual rainfall around the Harbour is about 1210 mm (Mosman 1221 mm, Manly 1218 mm, Observatory Hill 1213 mm), with only Rodd Island much further inland, substantially lower (Ashfield 1069 mm). Natural vegetation is mainly coastal sclerophyll heath and scrub on shallow, sandy soils on the large headlands with ocean shorelines and exposed to onshore winds (North, South and Dobroyd Heads), and eucalypt woodland on the more sheltered harbourside slopes of North Head. Perched deposits of leached white sand on the top of North Head (83 m elevation) have remnants of the Endangered Ecological Community Eastern Suburbs Banksia Scrub, structurally similar to the coastal heath but on lower nutrient sand (Benson & Howell 1990, 1994). The more sheltered foreshore headlands of the harbourside precincts, Middle, Chowder, Bradleys Heads and Nielsen Park, have more extensive areas of woodland. Recent work by NSW Dept of Environment Climate Change and Water has described fine scale map units but has not yet been finalised.

Methods

A list of all native flora species (except non-vascular plants and fungi) for Sydney Harbour National Park showing recorded occurrence within the seven major regions/ precincts (North Head, South Head, Dobroyd Head, Middle Head, Chowder Head, Bradleys Head and Nielsen Park) was compiled. This was based on available historical species lists (principally Bradley 1972, Holland (1980), Horton & Benson (1986), Skelton et al 2003), together with records from DECCW

Table 2 Mainland precinct/subregions of Sydney Harbour National Park ordered by area (ha), showing aspect, number of native plant species (including historical records), and number of single record species.

Precinct /region	Area (ha)	Aspect	No of species	Percent of flora	Single record species
North Head (Fed Trust 72 ha not incl.)	183	Ocean-influenced	351	86%	90
Dobroyd Head	65	Ocean-influenced	222	55%	15
Middle Head incl Clifton Gardens (13 ha)	52	Sheltered harbour	99	24%	6
Bradleys Head	31	Sheltered harbour	157	39%	5
Nielsen Park	24	Sheltered harbour	112	28%	11
South Head	16	Ocean-influenced	51	13%	1
Chowder Head	9	Sheltered harbour	120	29%	2
Total	**380**		**406**		**131**

Table 3 Number of species showing distribution by frequency classes (recorded on the seven mainland precincts/regions)

	Frequent /widespread (7, 6 or 5 sites)	Occasional (4 or 3)	Localised (2)	Single site	Total species (%)
Dicots	50	72	70	75	267 (66)
Monocots	10	25	27	50	112 (27)
Conifers	0	1	0	1	2 (<1)
Ferns	2	10	6	7	25 (6)
Total no of species (%)	**62** (15%)	**108** (26%)	**103** (25%)	**133** (33%)	**406**

Atlas, specimen data from the National Herbarium of New South Wales (NSW) and recent field work by the author for Bradleys, Chowder and South Heads and Nielson Park. Species names follow current PlantNet, the online listing of the National Herbarium of New South Wales.

The initial list was reviewed to remove species that were not part of the native indigenous flora, mainly exotic weed species, but also native species not indigenous to the area, but which occur there as a result of natural colonisation from planted sources or as plantings themselves e.g. *Nephrolepis cordifolia, Lophostemon confertus*. These were listed separately.

Based on the occurrence of species on the seven precinct headland areas, species were grouped by frequency as *Frequent/widespread* (recorded from 7, 6 or 5 areas) *Occasional* (4 or 3 areas) and *Localised* (2 areas). Species recorded from only a single site were identified as Single or Single-unsubstantiated. For these species records for the Sydney Harbour and immediate Sydney area were checked for the presence of historical herbarium specimens to confirm their indigenous status. Species recorded from a number of sites and/or sources were not checked individually unless there was a reason to confirm their indigenous status, as it was assumed the multiple site recording gave the species some conservation protection and multiple sources provided reasonable identification validity. Species reported in the sources but for which no current or historic specimens exist were listed as being of questionable/non-local status.

Some First Fleet accounts (Bradley 1969, Worgan 1978) were specifically consulted to provide historical context to the lists but the author has been familiar with the subject of 19th Century botanical/ecological material for the Sydney area for many years and is aware of the little species specific material that is available (e.g. see Benson & Howell 1990). Indeed interesting material is likely to turn up fortuitously from obscure places by way of colleagues and interested readers, rather than being amenable to targeted searching.

Results

List of plant species indigenous to Sydney Harbour National Park

From an initial listing of c 600 species names, a final list of 406 species (taxa) was extracted. (Appendix 1). Species listed are primarily dicotyledons (66%) and monocotyledons (27%) with a few ferns (6%) and two conifers (Table 3). These species are regarded as indigenous to the bushland areas of Sydney Harbour National Park, including the Sydney Harbour Federation Trust lands on North Head (but excluding the islands) and are species that are considered likely to have been represented there in

1788. The list includes historical records; not all species are necessarily still surviving in the Park in 2010.

A list of (questionable/non-local) species which have been referred to in some literature sources but which are not likely to be part of the indigenous Sydney harbour flora for various reasons, or are unlikely and are not substantiated with a herbarium record was also compiled (Appendix 2). Species on this list may be there for a variety of reasons – some small-growing plant species may be recognised in surveys but have not been formally collected even in historic times, some species may have now disappeared from the area as a result of historical changes (they may turn up at some future time), some species are likely to have been introduced as plantings, some are misidentifications of related species, or clear misidentifications. For a number of species, deciding whether it is likely to be indigenous to the Sydney Harbour National Park area has been difficult. For example Bradley (1972) records *Telopea speciocissima no flower Only 1 plant* at Ashton Park on Bradleys Head. As this is normally a particularly prominent plant (the Waratah) and there are no collections historic or otherwise to confirm this identification, or whether it is a planting, the species has been put in the questionable/non-local list. Additional evidence is that the usual habitat (suitable deep ridgetop sandy loam) is not present in the Park. Future confirmation of these species with a specimen representing an evidently naturally occurring population may allow them to be added to the formal list.

The listings raise the issue of the role of herbarium collections in verifying changes in vegetation. In confirming some single record species it became evident that, though there are historical 19th Century specimen collections from the general Sydney harbour area for many of them, very few species are substantiated by recent herbarium collections. There has frequently been the presumption that because the area is so well known it is not necessary to collect material that would generally be collected in a similar survey of an area further afield. Given the 100 year interval and the degree of changes wrought in that time it is appropriate that a current collection of herbarium specimens be made as an update of the baseline database.

The results also highlight common collector biases. Large shrubs, distinctive species and shrubs in particular are well recorded but ground plants and particularly monocot species are likely to be under-recorded. Despite their size eucalypts are often overlooked because of difficulty of collection and identification.

Geographical distribution and species richness

The species are not distributed evenly between the seven geographical precincts of the Park. A few species are found in all subregions, many are found at only one (Appendix 1). Though only 2 species, *Banksia integrifolia* and *Allocasuarina distyla*, have been recorded at all seven precincts, 62 species (15% of the total list) were recorded to occur at 5,

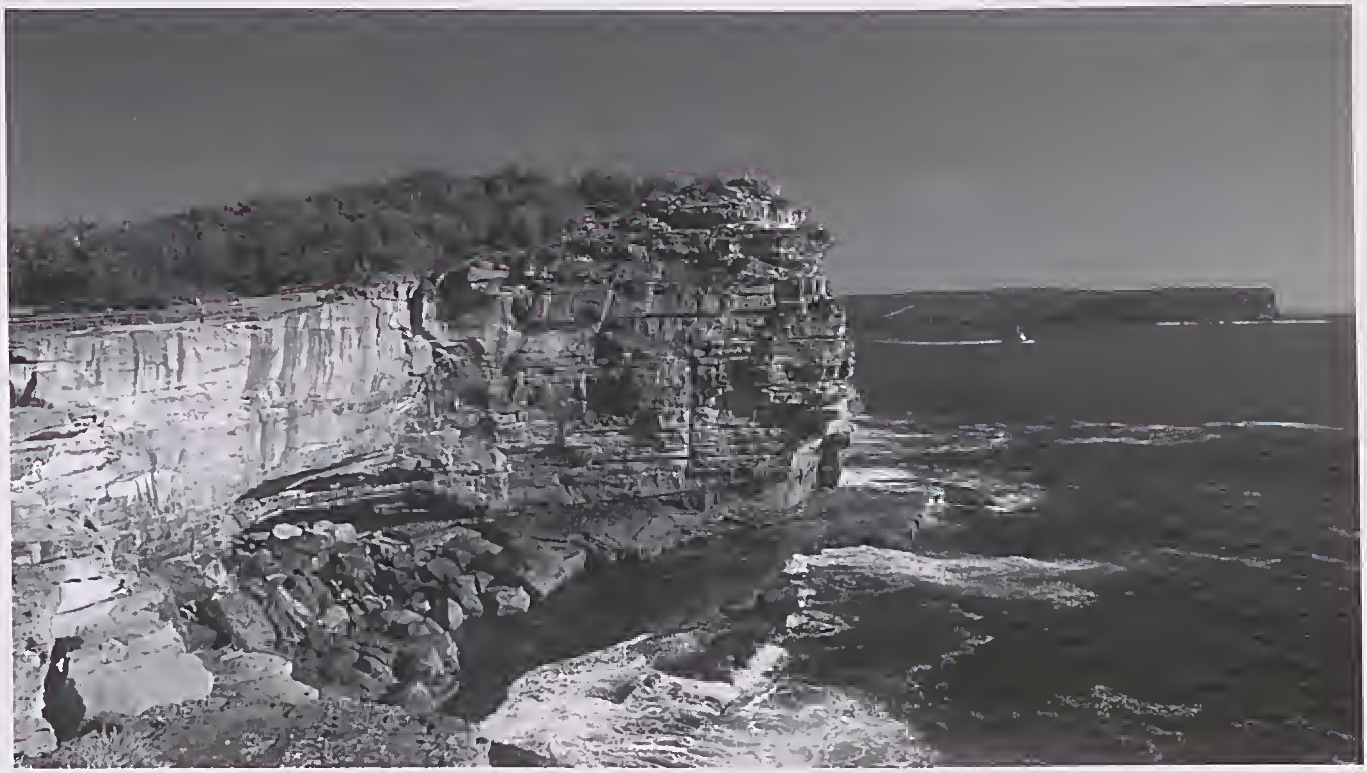

Fig. 2. The entrance to Sydney Harbour, looking from South Head with heath perched above its sandstone cliffs, across to North Head, the largest Sydney Harbour National Park precinct. Photo Jaime Plaza

Table 4 Significant ecological communities and flora species recorded in Sydney Harbour National Park and listed under state or national legislation.

Scientific Name	Status	Precincts recorded
Eastern Suburbs Banksia Scrub	Endangered Ecological Community -NSW TSC Act	North Head
Allocasuarina portuensis (Casuarinaceae)	Endangered Species NSW-TSC Act; National-EPBC Act	Nielsen Park
Acacia terminalis subsp. ***terminalis*** (Fabaceae)	Endangered Species NSW-TSC Act; National-EPBC Act	North Head, Nielsen Park
Chamaesyce psammogeton (Euphorbiaceae)	Endangered Species NSW-TSC Act	North Head, needs confirmation
Persoonia hirsuta (Proteaceae)	Endangered Species NSW-TSC Act National-EPBC Act	North Head 1967, needs confirmation
Eucalyptus camfieldii (Myrtaceae)	Vulnerable Species NSW-TSC Act; National-EPBC Act	North Head
Pimelea curviflora (Thymelaeaceae)	Vulnerable Species NSW-TSC Act; National-EPBC Act	North Head, South Head, needs confirmation
Syzygium paniculatum (Myrtaceae)	Vulnerable Species NSW-TSC Act; National-EPBC Act	Crater Cove, Dobroyd Head 1987 Needs confirmation

Table 5 Regionally significant flora species of Sydney Harbour National Park

Species (family)	Status for SHNP populations	Precincts recorded
Chordifex dimorphus (Restionaceae)	Substantial pop. of local Sydney coastal endemic (range Broken Bay to Cataract)	North Head
Melaleuca hypericifolia (Myrtaceae)	Disjunct and near northern limit of range	Dobroyd Head
Eucalyptus obstans (Myrtaceae)	Remnant pop. of previously common coastal Sydney species	
Hibbertia nitida (Dilleniaceae)	Pop. of local Sydney endemic - 2RC	North Head
Darwinia leptantha (Myrtaceae)	Important pop. of local Sydney coastal endemic (range North Head to Cronulla)	North Head
Erythrorchis cassythoides (Orchidaceae)	local disjunct popn, Regionally rare -3RC	North Head
Rulingia hermanniifolia (Sterculiaceae)	Important populations of coastal Sydney (Broken Bay to Botany Bay) distribution	North Head
Callitris muelleri (Cupressaceae)	Remnant pop. of previously common coastal Sydney species	?Middle Head
Gonocarpus salsoloides (Haloragaceae)	Uncommon coastal species near southern limit	North Head
Banksia aemula (Proteaceae)	Key component of ESBS, near southern limit	North Head
Styphelia spp. (Ericaceae)	Local pops now rare	
Pultenaea dentata (Fabaceae)	Local Sydney coastal endemic (range Coogee to Bundeena) that might occur in SHNP?	Not recorded
Platysace stephensonii (Apiaceae)	Local Sydney coastal species (range Broken Bay to Bundeena) that might occur in SHNP?	Not recorded

6 or 7 precincts; based on their frequency these species are considered *frequent/widespread* at this regional scale (Table 3). Species recorded in 3 or 4 precincts are considered as *occasional* (108 species, 26%) and species in 2 precincts as *localised* (103 species, 25%). About 133 species (33%) were recorded at only one precinct. These species are important as they may be rare species with special habitat requirements. Alternatively they may be more common species that have been overlooked in some surveys because of their size or seasonal occurrence, or difficulty of identification.

Of the individual precincts North Head has the highest species richness with 351 species (86% of the total flora), followed by Dobroyd Head (222 species) (Table 1). It is no surprise that North Head has the greatest number of species as it has the biggest area (183 ha plus adjoining Federation Trust bushland), has a wide range of habitats, and has been the most thoroughly surveyed. The inner Harbour headland precincts range from Bradleys Head with 157 species to Middle Head with 99. The smallest precinct Chowder Head has 120 species. South Head has 51 species (13% of the total) including a rare or threatened species, *Pimelea curviflora*.

Perhaps different past treatments contribute to species differences though this is less likely given the coarseness of the recording. Absence of some species may have resulted from the amount of past disturbance the smaller areas have received particularly from 19th Century military fortifications on Middle Head, Bradleys Head and South Head. Military activities on North Head have been substantial since establishment of the artillery school in the1930s but have been mainly concentrated on the central area, now in the Sydney Harbour Federation Trust lands. Disturbance is generally indicated by an increased number of exotic species rather than fewer native species as many native species will still persist for some time in very disturbed sites.

Of the 132 single precinct record species, 69% (91 spp) are only recorded for North Head while Nielsen Park has 8% (11 spp) and Bradleys Head has 4% (5 spp) (Table 2). Together the four inner Harbour sites have 18% of the single record species reflecting a different range of local habitats; vegetation at North Head is mainly coastal heath and scrub while in the others is mainly harbourside woodland. An interesting observation to come out of the search of historic records is the high number of species now only recorded on North Head, mainly on deep sand in Eastern Suburbs Banksia Scrub, which were previously collected from Rose Bay in the late 19th Century, and presumably occupied the extensive sand deposit (now completely urbanised) that occurs between Rose Bay and Bondi. The high degree of correlation between clusters of species and soil/geological substrates is a major feature of vegetation patterns in eastern Australia.

Significant species

In an increasingly heavily-used recreation area such as Sydney Harbour National Park, and one that is now cut-off from other natural areas, the conservation status and condition of individual species will need to be monitored if populations of all species are to be maintained. A number of species are listed as threatened at national (*EP&BC* Act) and state (NSW *TSC* Act) level including *Allocasuarina portuensis, Acacia terminalis* subsp. *terminalis* and *Eucalyptus camfieldii*; management action is currently taken to ensure their longterm survival (Table 4). There are also regionally important species, based on some particular features such as unusual distribution, general uncommonness in the region, disjunct occurrences or at or near limits of range. (e.g. the population of *Melaleuca hypericifolia* in SHNP is near its northern geographical limit and is disjunct from populations in the upper Blue Mountains). These contribute to the overall importance of Sydney Harbour National Park to the national conservation reserve system. Benson and Howell (1994) included the following North Head species as having particular conservation significance; *Gonocarpus salsoloides, Darwinia leptantha, Banksia aemula*, and some additional ones are included in Table 5.

Table 6 Lost species: Flora species of Sydney Harbour National Park that have possibly gone locally extinct from the Park area (i.e. not recorded since 1950)

Species (family)	Last recorded
Astroloma pinifolium (Ericaceae)	North Head 1986, Bradleys Head 1845
Botrychium australe (Ophioglossaceae)	Georges Head 1914
Cassinia denticulata (Asteraceae)	Bradleys Head 1903
Conospermum tenuifolium (Proteaceae)	Manly 1902, 1880
Dendrophthoe vitelina (Loranthaceae)	Rose Bay 1885
Dipodium roseum (Orchidaceae)	Bradleys Head 1903
Gompholobium grandiflorum (Fabaceae)	Bradleys Head 1903
Melaleuca linariifolia (Myrtaceae)	Middle Head 1900
Muellerina celastroides (Loranthaceae)	Nielsen Park 1918
Muellerina eucalyptoides (Loranthaceae)	Nielsen Park 1918
Notothixos subaureus (Viscaceae)	Nielsen Park 1918
Orthoceras strictum (Orchidaceae)	Middle Head 1912
Podolobium ilicifolium (Fabaceae)	Middle Head 1802
Stylidium graminifolium (Stylidiaceae)	Bradleys Head 1903
Velleia lyrata (Goodeniaceae)	Bradleys Head 1903

These 27 species however make up only 6% of the total flora of Sydney Harbour National Park. A conservation management aim is to retain all species as healthy populations in their natural area; complementary measures to monitor the health of the other 389 species (94%) are therefore needed. While these species are generally considered to be adequately covered by general management of plant community conditions (through weed control, fire management and protection from disturbance), the high number of species and the degree of disturbance in Sydney Harbour National Park indicate that a targeting of a wider range of species to monitor for conservation adequacy is desirable.

Species abundance and conservation adequacy

The list of Sydney Harbour National Park species (Appendix 1) indicates only the presence of a species within a precinct. The list does not indicate the abundance of species within any precinct, as very little of the source material is from replicated sampling (an exception is the unpublished 1986 North Head data of Benson & Horton which listed frequency based on 180 sites). However precinct frequency can provide a measure of overall abundance applicable to conservation assessment, though it provides little specific information on ecological importance, population adequacy or health. In conservation terms the frequent/widespread and occasional species could therefore be considered as *least concern* (using IUCN classes), localised as *near threatened* and single occurrences as *vulnerable*.

Further sifting of the single-occurrence *vulnerables* could be based on field observations using criteria such as restricted location and small population size, and could further identify locally important 'indicator' species. Such uncommon species may indicate unusual habitat conditions (now localised but likely to have been previously more extensive), or a response to particular current environmental conditions (e.g. increased shading due to dense shrub overstorey growth, or unusually dry or wet conditions depending on the current climate cycle). Whether management action is required or not depends on individual cases, but such assessment should be part of a future vegetation monitoring program.

Lost species

Extracted from the main species list is a list of species (Table 6) for which there are only very old recordings, mostly pre-1920. These species may have become extinct since that time, or may still survive unnoticed. Possible reasons for localised extinctions may be that

- the Park included only marginal habitat (e.g. the species may have been formerly more widespread on the plateau and upper slopes now occupied by suburban houses – possibly applicable to *Conospermum tenuifolium, Velleia lyrata*, or
- the fertile creek alluvium habit now generally lost to fill for grassy lawns – *Melaleuca linariifolia*, or
- changes in local suitable habitat conditions – *Orthoceras strictum*, or
- changes in fire frequency *Podolobium ilicifolium, Gompholobium grandiflorum* or
- reduction of population size to unviable limits – *Cassinia denticulata, Stylidium graminifolium*; or
- perhaps deliberate removal *Notothixos subaureus, Muellerina celastroides* or
- a combination of the above.

These lost species (about 15 species) could be searched for as part of baseline audit and it would be good to find them. However reintroduction is not recommended at this stage unless the species is considered to contribute to a key ecological function and source material of appropriate genetic source is available. Given the early use of genetic testing due to lack of genetic uncertainty at this stage we should retain local provenances and concentrate our limited resources to ensuring that no more species are added to this list.

Historical evidence and trends – Sydney Harbour in 1788

In the natural eucalypt woodlands and rocky sandstone slopes of Sydney Harbour today, it is easy to recognise the Harbour landscape of 1788, as presented in the accounts of the First Fleet recorders. George Worgan, in his letter dated June 1788 continues.– *Here, a romantic rocky, craggy Precipice over which a little purling stream makes a Cascade There, a soft vivid-green shady Lawn attracts your Eye: Such are the prepossessing appearances which the country that forms Port Jackson presents successively to your View as You sail along it.* (Worgan 1978)

Surgeon Worgan and Lieutenant William Bradley visited a number of places around Sydney Harbour together and recorded aspects of the vegetation in their journals. For example the presence of heath, fire and aboriginal use on North Head was described on May 29 1788 – *a steep Rocky Hill, thickly covered with Brush-Wood.. observed a great Fire, which we found to be the burning of a Heathy brush-Wood, which we supposed the Natives has set on Fire for some Purpose* (Worgan 1978 p 49).

They recognised a number of characteristic trees including *Casuarina glauca* and *Livistona australis*, but particular eucalypts and Angophoras were not easy for them to distinguish separately. Bradley's journal includes a list of 12 trees recognised for various uses. Combined with references to other smaller species mentioned elsewhere in his journal, this list give an idea of how the species around the harbour were seen by the European colonists within the first two years of settlement (Table 7). The list shows that the origins of some of the confusing array of vernacular names subsequently applied to eucalypts, were established in the very first days of settlement.

As to the Shrubs and Plants and Herbs of this Country "Tis beyond the Power of Botanists to number up their Tribes. – Among the useful we have discovered, Balm, Parsley, Samphire, Sorrel & a kind of Spinnage, but, all indifferent in kind... a Shrub bearing a Fruit like a a Sloe, and here is a fruit which tastes exactly like the currant when green, but these Fruits are scarce. The Woods are decorated with a Variety of prettily coloured flowers, but there is not above 2 or 3 kinds that have any Fragrance I have seen a kind of Myrtle in some Spots. Such descriptions as this by Worgan (page 12) confirm the impact of the variety of shrub and small species present around Sydney Harbour in 1788, but are not adequate to allow any assessment of change since that time.)

Table 8 Native species recorded in the Outer Domain (Maiden 1902) and at Garden Island (Rodd & Benson 1986) that have not been recorded in Sydney Harbour National Park

Dicotyledons		
Acacia falcata	Fabaceae	Garden I. 1986
Acacia maidenii	Fabaceae	Domain1902
Calotis cuneifolia	Asteraceae	Domain1902
Cassinia cunninghamii	Asteraceae	Garden I. 1986
Cassinia longifolia	Asteraceae	Domain1902
Cassinia quinquefaria	Asteraceae	Domain1902
Crassula sieberiana	Crassulaceae	Domain1902
Daviesia acicularis	Fabaceae	Domain1902
Eucalyptus pilularis	Myrtaceae	Domain1902
Eucalyptus resinifera	Myrtaceae	Domain1902
Euchiton sphaericus	Asteraceae	Domain1902
Ficus aspera	Moraceae	Domain1902
Goodenia paniculata	Goodeniaceae	Domain1902
Hypericum gramineum	Clusiaceae	Domain1902
Hypoxis hygrometrica	Hypoxidaceae	Domain1902
Lythrum hyssopifolia	Lythraceae	Domain1902
Myoporum acuminatum	Myoporaceae	Domain1902
Pelargonium australe	Geraniaceae	Garden I. 1986
Polymeria calycina	Convolvulaceae	Domain1902
Poranthera microphylla	Euphorbiaceae	Domain1902
Portulacca oleracea	Portulacaceae	Domain1902
Rumex brownii	Polygonaceae	Domain1902
Solenogyne bellioides	Asteraceae	Domain1902
Monocotyledons		
Carex inversa	Cyperaceae	Domain1902
Cymbopogon refractus	Poaceae	Domain1902
Ficinia nodosa	Cyperaceae	Garden I. 1986
Fimbristylis dichotoma	Cyperaceae	Domain1902
Paspalum distichum	Poaceae	Domain1902
Sporobolus creber	Poaceae	Domain1902

Table 7 *List of Sydney trees (numbered 1–12) March 1791* compiled by William Bradley (Bradley p 232A and other species noted around the Harbour, with notes from Bradley and George Worgan (Worgan 1978)

The list shows that the origins of some of the confusing array of vernacular names subsequently applied to eucalypts, were established in the very first days of settlement. These names developed from a wide range of plant features, some recognisable in the landscape, but others noted in the working or use of the timber. Bradley uses names such as *ironwood* (ironbark), *peppermint, swamp mahogany* and *blue-barked gum tree* described by characters including *gum* on the outside of the trunk (as noted by Cook at Botany Bay) but also as veins in the wood; bark type as in blue-barked gum tree, timber characters as in hardness (ironwood), timber colour (mahogany); and leaf characters (peppermint taste). Names for other species used by Bradley include turpentine (named from bark characteristics) and honeysuckle (flower characteristics) and Tea tree (leaf use) and Sarsaparilla (liquorice leaf flavour).

Quotes from Bradley in italics		**Likely modern species**
1.*Gum Tree*	*The wood white, fit for little but the fire; largest is lofty and thick*	*Angophora costata*, Large eucalypts, scribbly gums,
2. Iron Wood	*Grows very tall & large all about; but near Rose Hill in particular,*	*Eucalyptus crebra, Eucalyptus paniculata*
3. Corkwood	*Grows near the sea, just within the harbour, none in land not even so far as Sydney…very scarce*	*?Endiandra sieberi*
4. The Peppermint Tree		*Eucalyptus piperita*
5. The Tea tree	*More fit for furniture*	*Leptospermum, Melaleuca*
6. The Swamp Mahogany	*Grows in or close to swamps* *A species of Mahogany does not grow so straight nor as tall* For building construction Worgan	*Eucalyptus robusta*
7. The High ground Mahogany	*Grows on higher ground…best wood for furniture*	
8. *Brown bark'd Gum Tree*	*Kangaroo Ground, Rose Hill…to the height of 80 or 100 feet without a branch*	*Eucalyptus pilularis*
9. *Blue bark'd Gum Tree*	*Little different from that last mentioned*	*Eucalyptus saligna, Eucalyptus tereticornis*
10. *Turpentine Tree*	*A kind of Turpentine is found between the bark & the timber ,grows all about to 40 or 50 feet high or more*	*?Syncarpia glomulifera*
11. *Pine Tree*	*leaves like a Fir, is remarkably straight* Bark used for canoes, Used for shingles Worgan p17	Clearly *Casuarina*; trees large enough and near water would have been *Casuarina glauca*
12. Honeysuckle	Flower contains a great quantity of honey…Grows in sandy & rocky…Does not often grow to more than 10 or 12 feet high	*Banksia serrata*
OTHER SPECIES		
a dwarfish tree -	bearing a Rush-like Leaf, the Trunk of which yields a Quantity of a yellowish Gum,… Worgan p 12	*Xanthorrhoea*
Cabbage-Trees –	*Cabbage-Trees abound here…straight to the Height of 70, 80 or 90 Feet.* Worgan p 11	*Livistona australis*
	a nut which grows in clusters	*Macrozamia communis*
	a kind of wild fig	*Ficus coronata*
	wild spinage	*Tetragonia tetragonoides*
	samphire	*Sarcocornia*
	parsley	*Apium prostratum*
	sorel	*Rumex brownii*
	wild celery	*Apium prostratum*
	A berry – Like a Currant	*Leptomeria acida*
Plant…amongst the underwood entwined –	*taste of Liquorish & serves both for tea and sugar*	*Smilax glyciphylla*

Full Quote *We found a kind of wild fig & notice that the natives use it; they also use a nut which grows in clusters to the size and shape of the tops of the pine, One of the convicts was poisoned by eating them, in what manner the Natives prepare them I do not know but I tasted some at Broken Bay & thought them good. We never met with the smallest appearance of any kind of cultivated ground; we found wild spinage, samphire & parsley & small quantity of sorel & wild celery, all of which with the leaves of several kinds of bushes were used by us for want of better vegetables which were not yet supplied from the gardens… Soon after our arrival a berry in appearance like an ?insipid Currant was found in many parts of the Harbour; a very strong pure acid & of infinite use in removing the scurvy from those on board who had been attacked by that disease: we also found a plant which grew about the rocks & amongst the underwood entwined, the leaves of which boiled made a pleasant drink & was used as Tea by our Ships Company; It has much the taste of Liquorish & serves both for tea and sugar. It is recommended as a very wholesome drink & a good thing to take to sea.* Bradley (1969) p 135, Oct 1788

The formal scientific description of Sydney plants was based on specimens sent back to Europe, beginning with specimens of Banks and Solander in 1770 (see Benson & Eldershaw 2007), and then those from various First Fleet gentlemen including John White and John Hunter (some common Sydney species were described by the English botanist Sir James Edward Smith from specimens sent by White before 1790). Interestingly the French expedition of La Perouse evidently collected specimens during the stay at Botany Bay in 1788, as remains of a cone of *Banksia serrata* have been identified in archaeological material from the wreck of the ships in the Solomon Islands (Morrison & Bark 2009).

During the 19th Century visiting botanists including Robert Brown, James Backhouse, Allan Cunningham and Ludwig Leichhardt made collections from the general Harbour area as it was easily accessible from Sydney. Such work lead to a scattering of species records from the 19th Century but no lists for a particular area at a particular time. The earliest list applicable to Sydney Harbour is a list of plants from the Outer Domain compiled by the Director of the Botanic Gardens Joseph Maiden in 1902 (Maiden 1902), which he compiled as a record anticipating that it would be cleared away after his time; it was. Although not part of Sydney Harbour National Park it included Mrs Macquaries Point, which would have had similar vegetation to Bradleys Head or Nielsen Park. Of the 95 species listed about 80% have been recorded in Sydney Harbour National Park. However interestingly 25 species occur that are not in Sydney Harbour National Park (Table 8). These are mostly small plants some indicative of open grassy sites (*Hypericum gramineum, Hypoxis hygrometrica, Lythrum hyssopifolium, Poranthera microphylla, Rumex brownii, Fimbristylis dichotoma* and *Sporobolus creber.* This most likely indicates a localised shale-influenced soil capping on the ridge along Mrs Macquaries Point but could be influenced by a particular management regime, such as light animal grazing or slashing as would be appropriate park management at that time. There are two tree species *Eucalyptus pilularis* (remnant trees still survive near the National Herbarium building) and *Eucalyptus resinifera.* There are four Asteraceae species including three *Cassinia* species – as Sydney Harbour National Park now only includes seven Asteraceae there appears to have been a significant loss of Asteraceae. The list also includes a few foreshore species (*Ficinia nodosa, Pelargonium australe*).

Non-indigenous native and exotic species

Changes over the last 100–150 years have clearly influenced the native flora. The clearing and sandstone earthworks associated with the 19th Century gun emplacements and fortifications, clearly destroyed local vegetation but the absence of exotic species would have allowed native species to colonise disturbed areas or persist in remnant bush, and subsequently recolonise when the areas became parkland. However with the development of adjacent suburbs such as Mosman in the early 20th Century, propagules of exotics of garden origin would have became available.

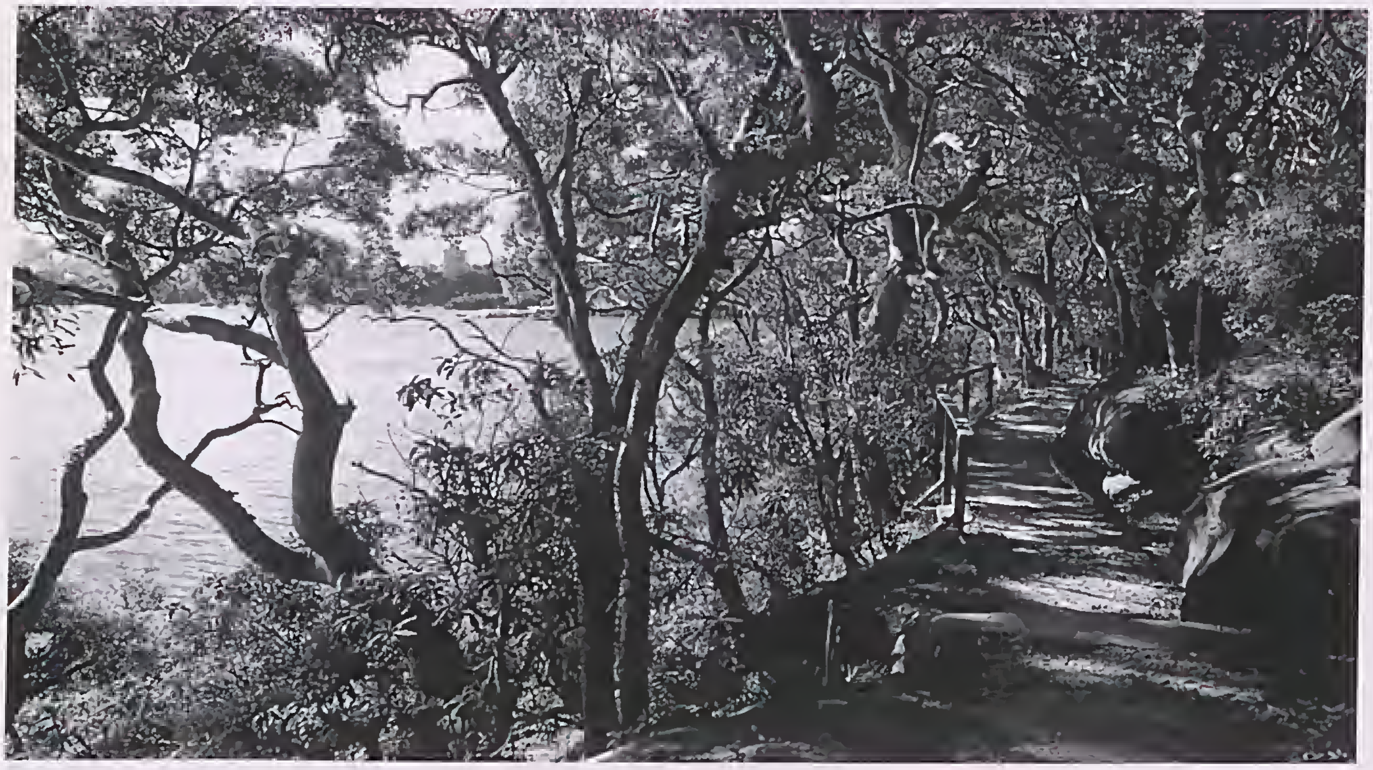

Fig. 3. A well-constructed track leads through *Angophora costata* woodland on sheltered harbour headland of Bradleys Head. Photo Jaime Plaza

The presence of exotic species in lists recorded since the 1960s (exotic weed species are not mentioned by Maiden in 1902) is evidence of the impact that naturalised exotic species are having on the natural habitats. Exotic weed species such as *Asparagus densiflorus*, *Crassocephalum crepidioides*, *Chrysanthemoides monilifera*, *Lantana camara*, *Ligustrum sinense* and *Ochna serrulata*, were all established at Bradleys Head – Chowder Head by 1972 (Bradley 1972). Generally regarded as originating as garden escapes, these species and others were probably also planted in gardens of military residences associated with the 19th Century military fortifications or the Ashton Park picnic areas in the early 20th Century. Impacts associated with suburban development particularly increased silt and nutrients in watercourses, and general spread of weeds in animal dung, provided habitats that suited the generally higher nutrient favouring exotics. Exotic birds as well as native ones provided dispersal for exotic fleshy fruits.

A number of native, but non-local species have also invaded parts of Sydney Harbour National Park as a result of changes providing new habitats, and/or cultivation in suburban gardens providing propagules (Appendix 3). These include *Nephrolepis cordifolia*, *Lophostemon confertus*, *Cyathea cooperi*, *Ficus macrophylla* and *Melia azedarach* which are clearly non-local. For some species that could be native to the area – *Christella dentata*, *Crinum pedunculatum*, *Cupaniopsis anacardioides*, *Cymbidium suave*, *Dendrobium speciosum*, *Pellaea falcata* and *Platycerium bifurcatum* – there are recent records but no evidence of historic occurrence. Some of these species may be a response to gardens as a source of propagules (*Cupaniopsis*, *Dendrobium*, *Cymbidium*, *Crinum* and /or the creation of new habitats such as road cuttings and quarries (*Christella* and *Platycerium*). These species are currently included in Appendix 2 as unsubstantiated.

In general the use of species lists to measure vegetation change is too coarse a measurement for specific ecological issues. The lists give no indication of abundances and rates of change. For example *Asparagus densiflorus* in particular has become a major weed along the harbour foreshores over the last 30 years (and is spreading in Pittwater) according to the author's observations. The increase in abundance of *Pittosporum undulatum* over a similar time has been much discussed (Howell 2003) but is native to Sydney and not a weed; though its relative abundance in absence of fire may inhibit less common native species.

Associated with suburban spread have come changes in fire frequency; initially an increase in burning and, as management becomes organised, a subsequent decrease. Bradley (1972) provides evidence of the problems with bush management in the 1970s Bradleys Head. Since that time a large amount of effort has gone into weed removal (by professional and volunteer groups), and control of stormwater, improvement of roads and walking tracks, now with often raised boardwalks to minimise disturbance and pathogens, and regeneration of disturbed sites in many parts of Sydney Harbour National Park.

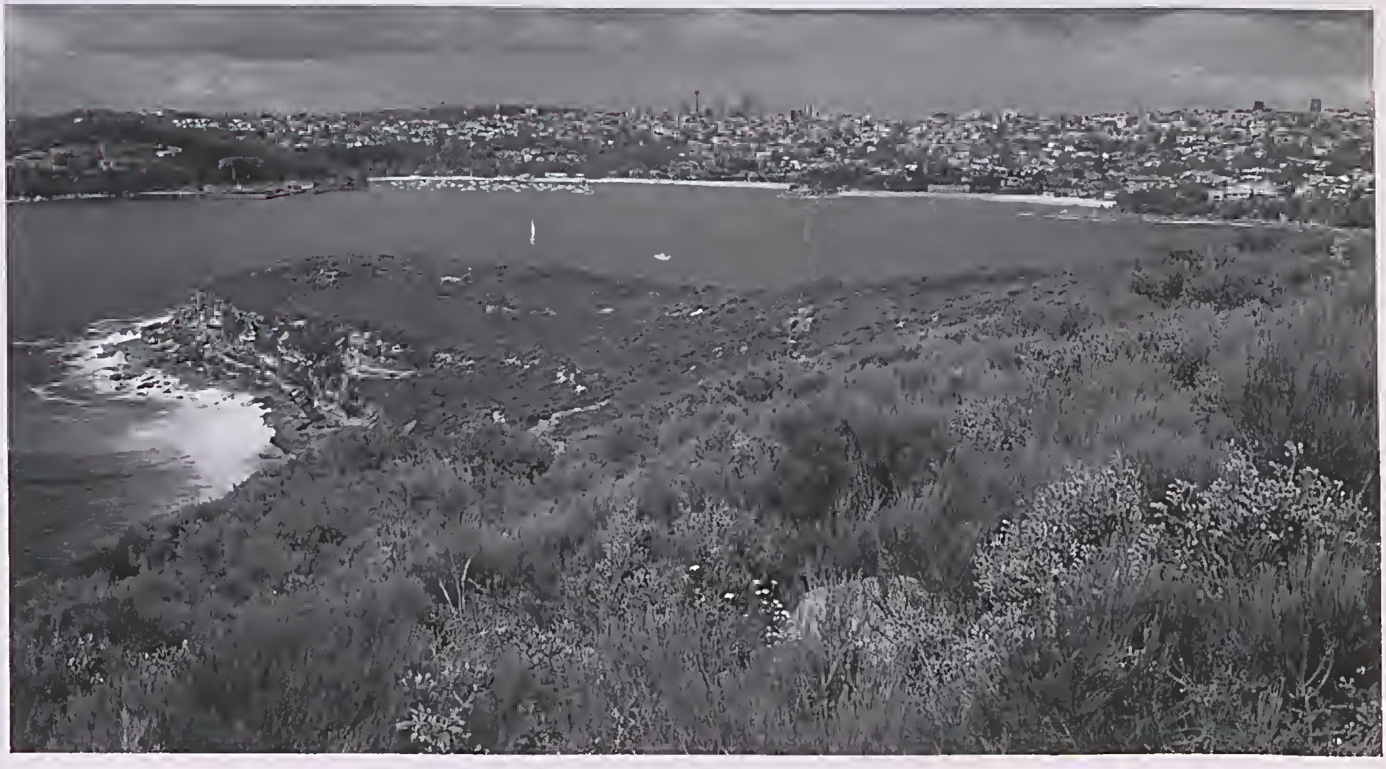

Fig. 4. One of the largest precincts of Sydney Harbour National Park, Dobroyd Head has extensive areas of coastal sandstone heath; shrubs of *Allocasuarina distyla* and *Banksia serrata* predominate in the foreground. Photo Jaime Plaza

The application of an appropriate fire regime in many areas is still problematical. After her experiences at Bradleys Head, Eileen Bradley (1972) wrote *Regardless of the time of year at which they occurred, high intensity fires have consistently induced such a powerful resurgence of native growth that reasonable time spent in weeding has resulted in vigorous clean bush, which, in itself, inhibits weed germination.* Because of small size of bushland areas, landscape features or proximity of housing, many areas of bushland have remained unburnt for 40 years or more. Since that time burns at Dobroyd Head and North Head in 2002 and at Bradleys Head in 2009, have been followed by good native regeneration and similar burns should be carried out elsewhere.

Discussion

Sydney Harbour has been acknowledged for its floristic abundance and landscape beauty since the writings of the First Fleet in 1788. For two centuries the sandstone cliffs of North Head and the woodlands of Bradleys Head and other harbour foreshores introduced ship-borne travellers to the landscape of New South Wales. Though arrivals are now by plane over Botany Bay (another icon area of Australian botany- see Benson & Eldershaw 2007), Sydney Harbour National Park now protects landscapes familiar to travellers on ferries and recreational boats, and suburban residents who are fortunate to overlook its areas; as well as providing the backdrop to many Harbour celebratory events. The tracks, lookouts and beaches are used by and familiar to many people. It is not surprising that issues impacting on its bushland (Bradley bushland techniques, weeds, low intensity burning, tree dieback from pollution, little penguins, bandicoots, *Phytophthora* and bushland volunteers) soon become part of Sydney's day-to-day knowledge.

Does the bushland of Sydney Harbour National Park deserve this attention?

For its size Sydney Harbour National Park has a rich diversity of plant species. The list of 416 native species from a 400 ha area is high; compare with Lane Cove National Park with 520 species in 600 ha (Kubiak 1983) or Ku-ring-gai Chase National Park with 566 spp in about 15 000 ha (Thomas & Benson 1985). Sydney Harbour also includes some rare species and locally restricted species, while clues in the lists also highlight the close relationship between native species and habitats, particularly through the fine geological and geomorphic variation originally evident in the landscape. Sydney Harbour National Park is a good example of the coastal sandstone parks of the Sydney Basin, and although its coastal landscape is less extensive than the larger Ku-ring-gai or Royal National Parks, it includes a range of vegetation types similar to the other Parks, and is more accessible.

Fig. 5. There are spectacular views over the ocean and harbour from of the tracks and lookouts in Sydney Harbour National Park such as from.Watsons Bay near South Head. Photo Jaime Plaza

As a key conservation area, are trends noted in Sydney Harbour National Park likely to promote responses further afield?

Sydney Harbour National Park has similar threat issues to other Sydney sandstone parks - weeds, low intensity burning, tree dieback from pollution etc. The work of Eileen and Joan Bradley in the 1970s was instrumental in highlighting the importance of weed control and bush regeneration, as well as drawing attention to fire in conservation reserves. Both issues were soon taken up for bushland areas in other parts of Sydney. Tree die-back at Bradleys Head, as well as impacting the famous Manly Beach Norfolk Island Pines provided impetus to improve the offshore sewage disposal. Listing of Endangered populations (Little Penguins and Bandicoots) and the Eastern Suburbs Banksia Scrub Endangered Ecological Community provided considerable publicity to the NSW Threatened Species Conservation Act soon after its passing in 1995. More recently the potential of *Phytophthora* to damage bushland in Mosman has led to further surveys in the wider Sydney area and Blue Mountains. Perhaps impacts of climate change on natural populations will be noted and first publicised through impacts around Sydney Harbour? Records from Fort Denison (now part of Sydney Harbour National Park) document a rise in sea level since the 1920s, while the need for increasing repairs to stonework at water-level are an indication of future costs.

The isolated positions of Sydney Harbour National Park's seven separate terrestrial headland precincts, each with large adjoining urban interfaces, differs from the contiguous areas of the large national parks, but pose similar problems to those of many small reserves, particularly council areas in other parts of Sydney such as Middle Harbour, Botany Bay, Georges River and Port Hacking. However the Harbour headlands are not as impacted as reserves which are totally surrounded by developed areas, as natural harbour foreshore margins may make up more than half of their perimeters and although not allowing terrestrial plant and animal movement, nevertheless is a natural water connection and continues to allows natural movement of birds and invertebrates. Thus pollen and seed can still be transferred over water by birds or insects moving between the different precincts.

Indeed the different precincts may be used to highlight particular ecological and landscape differences between the ocean and harbour headlands, e.g. more coastal heath, particular coastal species *Westringia fruticosa, Melaleuca nodosa, Melaleuca hypericifolia* on coastal headlands contrasts with woodland on harbour headlands. Otherwise their individual isolated *island* status may be used as advantage e.g the North Head Sanctuary proposal, reintroduction of native rats to Bradleys Head /Middle Head (Peter Banks pers.comm.); maintenance of *Phytophthora* free zones where walkers disinfect footwear etc. The establishment of formal boundaries between natural bushland and garden/lawn (often heritage) areas is an issue that needs future consideration particularly near bushland rehabilitation projects.

There are few records of the vegetation of the actual islands, but it is reasonable to assume that it was similar to nearby headlands; possible differences might have been different fire histories during aboriginal times, or different bird nesting regimes. Reestablishment of native vegetation on some of them will maintain of connectivity for birds and invertebrates crossing the harbour;

Therefore how good is our current flora database? And is it adequate for an icon site?

No other part of Australia has had such a long history of continuous European contact, including the collecting of specimens and description of landscape, as Sydney Harbour. For most of this time, data collection has been unsystematic, but a considerable body of material including photographic and pictorial records exists. While Botany Bay has earlier collections (in the 1770 collections of Banks and Solander (see Benson & Eldershaw 2007)), 19th Century Botany Bay collections come from a wider, less clearly defined area, and that area (except for the Kurnell Peninsula) has been more thoroughly cleared for suburban development than the foreshores of Sydney Harbour. Similarly areas such as the Blue Mountains and Royal National Park have only limited historical collections (generally beginning from the late 19th Century) from widely dispersed sites.

However our current information database for Sydney Harbour National Park, tied strongly to lists and censuses, has limitations. Lists need to relate to a specific time period to be useful, not just a continual accretion of species. Species lists are frequently confounded with multiple listings of misidentifications of the same species, which in the absence of specimen material are impossible to delete without at least reasonably targeted sampling for checking. However lists are very useful for promotion of conservation issues and public awareness feedback to support evidence-based adaptive management strategies. Lists can provide summaries of biodiversity values, rare and threatened species, regionally rare species, keystone species, conservation flags, and provide a basis for production of booklets/databases e.g. see Bear (2010) for Kurnell Peninsula.

A major emerging issue is the way in which we go about intergenerational transfer of knowledge. In biodiversity conservation there is a trend from individual expert-based systems with limited but flexible knowledge, to institutional databases with more extensive data (though not in this case so far), but lacking on-the-ground expert judgement and temporal experience. There is also a separation between databases (in institutions) and the body of public knowledge (distributed between various local knowledgeable people and organisations such as the North Head Sanctuary Foundation). Data needs to be shared both ways and acted upon through common understanding. A common body of data is needed that can be updated through both professional and community input

Conclusion

Sydney Harbour National Park is a key conservation site in terms of public prominence and accessibility. Its plant species and natural vegetation condition is the major asset but is vulnerable to an ongoing range of encroaching threats and warrants a higher amount of monitoring and management than is currently the case. Its current resource information base for plant biodiversity is limited and money spent on research, and development of monitoring programs in Sydney Harbour National Park are likely to result in high profile publicity and application in similar areas elsewhere.

This list provides a reasonably definitive list of the species occurring in the Park regions at the beginning of the 21st Century, but what is primarily needed is a systematic survey with site/quadrat based methodology available for future resurvey for State of Park trends.

Acknowledgements

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References

Anderson, D.J., Myerscough, P.J. & Pitman, M.G. (1981) Die-back of vegetation in the Central Coast Region. (report for NSW Dept of Public Works & Wyong Shire Council).

Bear, Virginia (2010) *Kurnell Peninsula: a guide to the plants, animals, ecology & landscapes.* (Sydney Metropolitan Catchment Management Authority: Parramatta).

Benson, D. & Eldershaw, G. (2007) Background to encounter: the 1770 landscape of Botany Bay, the plants collected by Banks and Solander and rehabilitation of natural vegetation at Kurnell. *Cunninghamia* 10(1) 113–137.

Benson, D. & Howell, J (1994) The natural vegetation of the Sydney 1:100 000 map sheet. *Cunninghamia* 3(4): 677–787.

Benson & Howell 1990) *Taken for granted: the bushland of Sydney and its suburbs* (Revis. edit 1995) (Kangaroo Press: Kenthurst) (available as pdf on Royal Botanic Garden website).

Bradley, E. & Bradley J, (1967) *Weeds and their control* (Mosman Parklands & Ashton Park Association).

Bradley, Eileen (1972) *Fires in Mosman Bushland* (E & J Bradley: Mosman).

Bradley, William (1969) *A voyage to New South Wales: the Journal of Lieutenant William Bradley RN of HMS Sirius 1786–1792* (Facsimile edit. William Dixson Foundation Publication no 11: Ure Smith, Sydney).

Buchanan, R.A. (2009) *Restoring natural areas in Australia* (NSW Dept of Industry & Investment).

Clark, M.S. & Clark, J. (2000) *The islands of Sydney Harbour* (Kangaroo Press: Sydney).

Clemens, J & Franklin, M.H. (1980) A description of coastal heath at North Head, Sydney Harbour National Park: impact of recreation and other disturbance since 1951. *Australian Journal of Botany* 28: 463–478.

Daniel, R, Taylor, J & Guest, D (2006) Distribution and occurrence of *Phytophthora cinnamomi* at Middle Head and North Head, Sydney Harbour. *Australasian Plant Pathology* 35: 569–571.

Morrison, Doug & Bark, Ivan (2009) Dagelet and Dawes: their meeting, their instruments and the first scientific experiments on Australian soil. *Historical Records of Australian Science* 20: 1–40.

Holland, Dorothy (1980) Mount Trefle: a general and botanical study within Sydney Harbour National Park. (unpub. Copy in RBG Library).

Horton, S. & Benson, D. (1986) A vegetation survey of North Head (Unpub. report for National Parks & Wildlife Service).

Howell, Jocelyn (2003) *Pittosporum undulatum* as a case study for native species that change range – how to avoid inappropriate responses? *Cunninghamia* 8(1): 153–155.

Kubiak, P. 1983 Species lists for the Lane Cove Valley (Unpub. lists held by the Royal Botanic Gardens Sydney).

Maiden, J.H. (1902) *Annual Report for Botanic Gardens and Domains for year 1902.* Species list also available in E. Wilson (1982) *Discovering the Domain* (Hale & Iremonger).

NSW National Parks & Wildlife Service (2000a) *Endangered Population of Little Penguins (Endyptula minor) at Manly Recovery Plan.* Prepared in accordance with the NSW Threatened Species Conservation Act 1995.

NSW National Parks & Wildlife Service (2000b) *Endangered Long-nosed Bandicoot Population at North Head.* Threatened Species Information sheet.

Pratten, C. & Benson, D. (1985) pages 44–49 in J.S. Kerr *Goat Island: an analysis of documentary and physical evidence and an assessment of significance.* Maritime Services Board of NSW (1985).

Rodd, A.N. & Benson, D.H. (1977) *Garden Island Dockyard – botanical survey* (unpub. Copy in RBG Library).

Skelton, N., Richmond, O., Gilson, T. & Wong, P. (2003) *Flora of North Head.* Prepared for the Sydney Harbour Federation Trust by GIS Environmental consultants, North Curl Curl.

Thomas J. & Benson, D. (1985) *Vegetation survey of Ku-ring-gai Chase National Park* (Royal Botanic Gardens Sydney).

Worgan, George.B. (1978) *Journal of a First Fleet surgeon* (Library of Australian History, William Dixson Foundation Publication No 16: 1978).

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Appendix 1. Native plant species recorded for Sydney Harbour National Park by precincts indicating distribution and historical period of record

1=19th cent record; 2= 1900–1949; 3=1950–1999; 4=2000–2010

Compiled from NSW National Herbarium and other records by Doug Benson, December 2010

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
FERNS									
Adiantaceae	*Adiantum aethiopicum*	occasional	3,4	4	2		3,4		
Aspleniaceae	*Asplenium australasicum*	occasional	3,4	4			3,4		3
Aspleniaceae	*Asplenium flabellifolium*	occasional	4		2	2	4		
Blechnaceae	*Blechnum ambiguum*	localised	3,4	2					
Blechnaceae	*Blechnum cartilagineum*	occasional	4	4		3	4		
Blechnaceae	*Doodia caudata*	single locality-uns rec		4					
Cyatheaceae	*Cyathea australis*	localised	4				4		
Davalliaceae	*Davallia solida* var. *pyxidata*	occasional	3,4	4		3			3
Dennstaedtiaceae	*Histiopteris incisa*	occasional	3,4	4		4			3,4
Dennstaedtiaceae	*Pteridium esculentum*	frequent/widespread	3,4	4	4	3,4	3,4	4	3,4
Dicksoniaceae	*Calochlaena dubia*	frequent/widespread	3,4	4	2,4	3,4	3,4		3,4
Gleicheniaceae	*Gleichenia dicarpa*	occasional	3,4	4	4	4			
Gleicheniaceae	*Gleichenia microphylla*	single locality-uns rec	4						
Gleicheniaceae	*Gleichenia rupestris*	occasional	3,4	4				4	
Gleicheniaceae	*Sticherus flabellatus* var. *flabellatus*	localised	4		4				
Lindsaeaceae	*Lindsaea linearis*	occasional	3,4	2		3			
Lindsaeaceae	*Lindsaea microphylla*	single locality-uns rec		4					
Ophioglossaceae	*Botrychium australe*	single locality			2				
Osmundaceae	*Todea barbara*	localised	3,4	4					
Polypodiaceae	*Pyrrosia rupestris*	occasional	4	4					3
Psilotaceae	*Psilotum nudum*	single locality-uns rec	4						
Schizaeaceae	*Schizaea bifida*	single locality-uns rec	3,4						
Schizaeaceae	*Schizaea dichotoma*	single locality-uns rec	4						
Selaginellaceae	*Selaginella uliginosa*	localised	3,4		4	4			
Sinopteridaceae	*Cheilanthes sieberi*	localised-uns rec	3						3
CONIFERS									
Cupressaceae	*Callitris muelleri*	single locality					4		
Podocarpaceae	*Podocarpus spinulosus*	occasional	3,4	4		3,4	4		
DICOTYLEDONS									
Aizoaceae	*Tetragonia tetragonoides*	occasional	4	4		4			3
Apiaceae	*Actinotus helianthi*	frequent/widespread	3,4	3,4			3,4	2,4	3
Apiaceae	*Actinotus minor*	occasional	3,4	1,4	1				
Apiaceae	*Centella asiatica*	frequent/widespread	3,4	4	1,4		4		3
Apiaceae	*Hydrocotyle peduncularis*	frequent/widespread	3,4	4	4			4	3,4
Apiaceae	*Platysace ericoides*	localised-uns rec	4	4					
Apiaceae	*Platysace lanceolata*	frequent/widespread	3,4	4	3	3,4	3,4	4	3,4
Apiaceae	*Platysace linearifolia*	occasional	3,4	4			2,4		
Apiaceae	*Pomax umbellata*	frequent/widespread	3,4	4		3,4	3,4		3,4
Apiaceae	*Xanthosia pilosa*	frequent/widespread	3,4	4	1	3,4	3,4	4	3,4

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Apiaceae	*Xanthosia tridentata*	occasional	3,4	4		3	3,4		
Apocynaceae	*Marsdenia suaveolens*	localised	3,4			3			
Apocynaceae	*Parsonsia straminea*	single locality-uns rec	4						
Araliaceae	*Astrotricha floccosa*	occasional	3,4		4		3,4		3
Araliaceae	*Polyscias sambucifolia*	frequent/widespread	4	4		3,4	3,4		3,4
Asteraceae	*Cassinia denticulata*	localised		4			2,4		
Asteraceae	*Cotula australis*	single locality-uns rec	3,4						
Asteraceae	*Epaltes australis*	single locality-uns rec	4						
Asteraceae	*Helichrysum scorpioides*	localised				3	3		
Asteraceae	*Olearia tomentosa*	occasional	3,4	4		4		4	
Asteraceae	*Ozothamnus diosmifolius*	occasional		4			3,4		3
Asteraceae	*Senecio hispidulus*	localised				3	3		
Baueraceae	*Bauera rubioides*	occasional	3,4	4			4		
Bignoniaceae	*Pandorea pandorana*	frequent/widespread	3,4	4		3,4	3,4	4	3,4
Campanulaceae	*Wahlenbergia gracilis*	single locality-uns rec	4						
Casuarinaceae	*Allocasuarina distyla*	frequent/widespread	3,4	3,4	3,4	3,4	4	2	3,4
Casuarinaceae	*Allocasuarina littoralis*	frequent/widespread	3,4	4	2,4	2,4	4		3
Casuarinaceae	*Allocasuarina portuensis*	single locality							4
Casuarinaceae	*Casuarina glauca*	occasional	3,4	4		4	4		3
Chenopodiaceae	*Rhagodia candolleana* subsp. *candolleana*	single locality-uns rec		4					
Chloanthaceae	*Chloanthes stoechadis*	occasional	3,4	4			4		
Convolvulaceae	*Dichondra repens*	localised	3,4	4					4
Crassulaceae	*Crassula decumbens var decumbens*	localised	4				3		
Cunoniaceae	*Callicoma serratifolia*	occasional	3,4	4			3,4		
Cunoniaceae	*Ceratopetalum gummiferum*	frequent/widespread	4	4	3	3,4	3,4		3
Dilleniaceae	*Hibbertia aspera*	single locality-uns rec		4					
Dilleniaceae	*Hibbertia dentata*	frequent/widespread	4	4	2,4	3,4	3,4	4	
Dilleniaceae	*Hibbertia empetrifolia* subsp. *empetrifolia*	localised	3,4	4					
Dilleniaceae	*Hibbertia fasciculata*	localised	3,4	4					
Dilleniaceae	*Hibbertia linearis*	occasional	3,4	4		3	4		
Dilleniaceae	*Hibbertia scandens*	frequent/widespread	3,4	4	2	3	3,4	4	
Droseraceae	*Drosera auriculata*	single locality-uns rec	3						
Droseraceae	*Drosera binata*	single locality-uns rec	3,4						
Droseraceae	*Drosera peltata*	localised	3,4			3			
Droseraceae	*Drosera spatulata*	single locality-uns rec	3,4						
Elaeocarpaceae	*Elaeocarpus reticulatus*	frequent/widespread	3,4	4	2	2,3,4	3,4		3,4
Elaeocarpaceae	*Tetratheca ericifolia*	single locality-uns rec	4						
Ericaceae	*Astroloma humifusum*	single locality-uns rec	3,4						
Ericaceae	*Astroloma pinifolium*	localised	3				1		
Ericaceae	*Brachyloma daphnoides*	localised	3,4	4					
Ericaceae	*Epacris crassifolia*	single locality-uns rec	3,4						
Ericaceae	*Epacris longiflora*	frequent/widespread	3,4	4	4	3,4	3,4	4	3,4
Ericaceae	*Epacris microphylla*	localised	3,4	3,4					
Ericaceae	*Epacris obtusifolia*	single locality-uns rec	3,4						
Ericaceae	*Epacris pulchella*	localised-uns rec	4	4			3		
Ericaceae	*Leucopogon amplexicaule*	localised	3,4	4					
Ericaceae	*Leucopogon ericoides*	localised	3,4	4					
Ericaceae	*Leucopogon esquamatus*	localised	3,4	4					
Ericaceae	*Leucopogon microphyllus*	localised	3,4	4					
Ericaceae	*Leucopogon parviflorus*	single locality					4		
Ericaceae	*Monotoca elliptica*	frequent/widespread	3,4		4	3,4	3,4	4	3,4
Ericaceae	*Monotoca scoparia*	single locality-uns rec	3,4						
Ericaceae	*Sprengelia incarnata*	single locality-uns rec	3,4						
Ericaceae	*Styphelia longifolia*	occasional	4		4	2	3,4		

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Ericaceae	*Styphelia triflora*	localised	3,4				3		
Ericaceae	*Styphelia tubiflora*	occasional	3,4	4			4		
Ericaceae	*Styphelia viridis* subsp. *viridis*	single locality-uns rec	4						
Ericaceae	*Woollsia pungens*	localised	3,4	4			4		
Euphorbiaceae	*Amperea xiphoclada* var. *xiphoclada*	localised	3,4			3			
Euphorbiaceae	*Breynia oblongifolia*	frequent/widespread	3,4	4		3,4	4		3
Euphorbiaceae	*Chamaesyce psammogeton*	TSC Endang. single locality-uns rec	4						
Euphorbiaceae	*Glochidion ferdinandi*	frequent/widespread	3,4	4	3,4	4	3,4	4	3,4
Euphorbiaceae	*Micrantheum ericoides*	occasional	3,4	4			4		
Euphorbiaceae	*Monotaxis linifolia*	single locality-uns rec	4						
Euphorbiaceae	*Omalanthus populifolius*	frequent/widespread	3			3,4	4	4	3,4
Euphorbiaceae	*Phyllanthus hirtellus*	frequent/widespread	3,4	4	2	2,3,4	3,4		
Euphorbiaceae	*Poranthera ericifolia*	localised	3,4			3			
Euphorbiaceae	*Pseudanthus orientalis*	single locality-uns rec	3,4						
Euphorbiaceae	*Ricinocarpos pinifolius*	occasional	3,4	3,4	2	2,3,4			
Fabaceae	*Acacia implexa*	localised		4	4	4	4		
Fabaceae	*Acacia linifolia*	frequent/widespread	3,4	4	2	2,3,4	3,4		
Fabaceae	*Acacia longifolia* subsp. *longifolia*	occasional			2,4	2,3,4	3,4		3,4
Fabaceae	*Acacia longifolia* subsp. *sophorae*	occasional	3,4	4				4	
Fabaceae	*Acacia myrtifolia*	occasional	3,4	4		3	3		
Fabaceae	*Acacia parramattensis*	localised	4	4					
Fabaceae	*Acacia quadrilateralis*	localised	4					2	
Fabaceae	*Acacia suaveolens*	frequent/widespread	3,4	4	2,3	2,3,4	3	4	3,4
Fabaceae	*Acacia terminalis* incl. *subsp terminalis*	frequent/widespread	3,4	4	4	3,4	3,4	3	3,4
Fabaceae	*Acacia ulicifolia*	frequent/widespread	3,4	4	2,4	2,3	3,4		3
Fabaceae	*Aotus ericoides*	single locality-uns rec	4						
Fabaceae	*Bossiaea ensata*	occasional	4	4	1				
Fabaceae	*Bossiaea heterophylla*	localised	3,4	4					
Fabaceae	*Bossiaea scolopendria*	single locality-uns rec	3,4						
Fabaceae	*Dillwynia floribunda*	localised	3,4	4					
Fabaceae	*Dillwynia retorta species complex*	frequent/widespread	3,4	4	3	3,4	3		3
Fabaceae	*Glycine clandestina/tabacina*	occasional	3,4			3	3,4		3
Fabaceae	*Glycine microphylla*	localised	4	4			3		
Fabaceae	*Gompholobium glabratum*	single locality-uns rec	4						
Fabaceae	*Gompholobium grandiflorum*	single locality-uns rec	3,4						
Fabaceae	*Gompholobium latifolium*	occasional	3,4	4		4	3		3
Fabaceae	*Hardenbergia violacea*	frequent/widespread	3,4		1	3,4	3,4		3,4
Fabaceae	*Hovea linearis*	single locality-uns rec		4					
Fabaceae	*Hovea longifolia*	single locality		4					
Fabaceae	*Kennedia rubicunda*	frequent/widespread	3,4	4	2	3,4	3,4	4	3,4
Fabaceae	*Mirbelia rubiifolia*	localised	3,4		3				
Fabaceae	*Oxylobium cordifolium*	single locality							3
Fabaceae	*Phyllota phylicoides*	single locality-uns rec	3,4						
Fabaceae	*Platylobium formosum*	frequent/widespread		4	2	3,4	3,4		3
Fabaceae	*Pultenaea daphnoides*	occasional	3,4		3		4		3
Fabaceae	*Pultenaea flexilis*	occasional	4	4			4		
Fabaceae	*Pultenaea linophylla*	single locality-uns rec	4						
Fabaceae	*Pultenaea retusa*	localised	3,4						3
Fabaceae	*Pultenaea stipularis*	localised	4				4		
Fabaceae	*Pultenaea tuberculata*	occasional	3,4	4			2		
Fabaceae	*Viminaria juncea*	frequent/widespread	3,4	4		3	3		3
Goodeniaceae	*Dampiera stricta*	occasional	3,4	4			4		
Goodeniaceae	*Goodenia bellidifolia*	localised	3,4	4					
Goodeniaceae	*Goodenia heterophylla* subsp. *eglandulosa*	localised	4	4			3		

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Goodeniaceae	*Goodenia stelligera*	single locality-uns rec	3,4						
Goodeniaceae	*Velleia lyrata*	single locality					2		
Haloragaceae	*Gonocarpus micranthus* subsp. *ramosissimus*	localised	3,4						3
Haloragaceae	*Gonocarpus salsoloides*	single locality-uns rec	3,4						
Haloragaceae	*Gonocarpus tetragynus*	localised	3,4						3
Haloragaceae	*Gonocarpus teucrioides*	frequent/widespread	3,4	4	4	3,4	3,4		3,4
Lamiaceae	*Hemigenia purpurea*	occasional	3,4	3,4			2		
Lamiaceae	*Plectranthus parviflorus*	occasional	3,4			3	4		3,4
Lamiaceae	*Westringia fruticosa*	frequent/widespread	3,4	4	3	4	3,4	4	3,4
Lauraceae	*Cassytha glabella*	localised	3,4						3,4
Lauraceae	*Cassytha pubescens*	occasional	3,4	1,4	4	4	2	4	
Lauraceae	*Endiandra sieberi*	localised	3,4						3
Lentibulariaceae	*Utricularia dichotoma*	single locality-uns rec	3,4						
Lobeliaceae	*Lobelia alata*	localised	3						3
Lobeliaceae	*Lobelia gracilis*	occasional	4			3	3		
Lobeliaceae	*Pratia purpurascens*	occasional		4		3			3
Loganiaceae	*Mitrasacme polymorpha*	localised	3,4	4					
Loranthaceae	*Amyema congener*	localised	3,4						2
Loranthaceae	*Dendrophthoe vitellina*	single locality							2
Loranthaceae	*Muellerina celastroides*	single locality							2
Loranthaceae	*Muellerina eucalyptoides*	single locality							2
Meliaceae	*Synoum glandulosum* subsp. *glandulosum*	occasional	3,4	4	4				
Menispermaceae	*Sarcopetalum harveyanum*	localised	3,4			3			
Menispermaceae	*Stephania japonica* var. *discolor*	occasional	3,4	4		4	4	4	
Moraceae	*Ficus rubiginosa*	occasional	3,4	4			4		3,4
Myoporaceae	*Myoporum boninense* subsp. *australe*	single locality							3
Myrsinaceae	*Myrsine variabilis*	occasional	3		4	4	4		3,4
Myrtaceae	*Acmena smithii*	occasional	3,4	4	4	4	4		
Myrtaceae	*Angophora costata*	frequent/widespread	3,4	4	4	3,4	3,4		3,4
Myrtaceae	*Angophora hispida*	occasional	3,4	4	4		2,4		
Myrtaceae	*Baeckea brevifolia*	single locality-uns rec	3,4						
Myrtaceae	*Baeckea diosmifolia*	localised	3,4	4					
Myrtaceae	*Baeckea imbricata*	occasional	3,4	3		4		4	3,4
Myrtaceae	*Callistemon citrinus*	single locality-uns rec	3,4						
Myrtaceae	*Callistemon linearis*	occasional	3,4	3,4	1			4	3
Myrtaceae	*Callistemon rigidus*	localised		4			3		
Myrtaceae	*Calytrix tetragona*	occasional	3,4	4	1				
Myrtaceae	*Corymbia gummifera*	occasional	3,4	3,4			4		3
Myrtaceae	*Darwinia diminuta*	single locality-uns rec	4						
Myrtaceae	*Darwinia fascicularis*	occasional	3,4	4	1			4	
Myrtaceae	*Darwinia leptantha*	single locality-uns rec	3,4						
Myrtaceae	*Eucalyptus botryoides*	frequent/widespread	3,4	4	4	3,4	3,4		3,4
Myrtaceae	*Eucalyptus camfieldii*	single locality-uns rec	3,4						
Myrtaceae	*Eucalyptus capitellata*	localised-uns rec	4	4					
Myrtaceae	*Eucalyptus haemastoma*	localised		4					3
Myrtaceae	*Eucalyptus obstans*	localised	3,4					2	
Myrtaceae	*Eucalyptus piperita*	occasional		4		3,4	4		3,4
Myrtaceae	*Eucalyptus punctata*	localised		4			4		
Myrtaceae	*Eucalyptus scias* subsp. *scias*	single locality-uns rec	4						
Myrtaceae	*Eucalyptus tereticornis*	single locality							3
Myrtaceae	*Eucalyptus umbra*	occasional	3,4	3,4					3
Myrtaceae	*Euryomyrtus ramosissima*	single locality-uns rec	3,4						
Myrtaceae	*Kunzea ambigua*	frequent/widespread	3,4	3,4	3,4	4	3,4	4	3,4
Myrtaceae	*Kunzea capitata*	localised	3,4	4					

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Myrtaceae	*Leptospermum arachnoides*	localised	3,4	3,4					
Myrtaceae	*Leptospermum juniperinum*	single locality-uns rec	3,4						
Myrtaceae	*Leptospermum laevigatum*	frequent/widespread	3,4	4			4	4	3,4
Myrtaceae	*Leptospermum polygalifolium*	occasional	3,4	3,4			3,4		3
Myrtaceae	*Leptospermum squarrosum*	occasional	3,4	3,4	2		4		
Myrtaceae	*Leptospermum trinervium*	frequent/widespread	3,4	3,4	2	2,3,4	3,4		
Myrtaceae	*Melaleuca armillaris* subsp. *armillaris*	occasional	3,4	4			3	1,4	
Myrtaceae	*Melaleuca hypericifolia*	localised	4	3,4					
Myrtaceae	*Melaleuca linariifolia*	localised	4		2				
Myrtaceae	*Melaleuca nodosa*	occasional	3,4					4	3,4
Myrtaceae	*Melaleuca quinquenervia*	occasional	3,4	4				1	
Myrtaceae	*Micromyrtus ciliata*	localised	4					2,4	
Myrtaceae	*Syncarpia glomulifera*	localised	3,4						3
Myrtaceae	*Syzygium paniculatum*	single locality-uns rec		3,4					
Olacaceae	*Olax stricta*	localised	3,4	4					
Oleaceae	*Notelaea longifolia f. longifolia*	occasional	3,4	4		4	4		3,4
Oleaceae	*Notelaea ovata*	occasional	4	4					3
Oxalidaceae	*Oxalis perennans*	single locality						3	
Peperomiaceae	*Peperomia blanda* var. *floribunda*	single locality							3
Pittosporaceae	*Billardiera scandens*	frequent/widespread	3,4	4		3,4	3,4		3,4
Pittosporaceae	*Pittosporum revolutum*	frequent/widespread	3,4	4	2,4	3,4	3,4		3,4
Pittosporaceae	*Pittosporum undulatum*	frequent/widespread	3,4	4	3,4	2,3,4	3,4	4	3,4
Polygalaceae	*Comesperma ericinum*	single locality-uns rec	3,4						
Polygalaceae	*Comesperma volubile*	single locality-uns rec		4					
Polygonaceae	*Persicaria decipiens*	single locality-uns rec		4					
Proteaceae	*Banksia aemula*	single locality-uns rec	3,4						
Proteaceae	*Banksia ericifolia* subsp. *ericifolia*	frequent/widespread	3,4	3,4	4		4		4
Proteaceae	*Banksia integrifolia*	frequent/widespread	3,4	4	3,4	3,4	3,4	4	3,4
Proteaceae	*Banksia marginata*	occasional	3,4					2	2
Proteaceae	*Banksia oblongifolia*	occasional	3,4	3,4			4		3
Proteaceae	*Banksia robur*	localised	3,4	4					
Proteaceae	*Banksia serrata*	frequent/widespread	3,4	4		3	3,4		3
Proteaceae	*Banksia spinulosa*	occasional		4	3	4	3		
Proteaceae	*Conospermum ellipticum*	localised	4		1				
Proteaceae	*Conospermum ericifolium*	occasional	4		1			1	
Proteaceae	*Conospermum longifolium* subsp. *longifolium*	single locality-uns rec	3,4						
Proteaceae	*Conospermum taxifolium*	single locality-uns rec	3,4						
Proteaceae	*Conospermum tenuifolium*	single locality			1				
Proteaceae	*Grevillea buxifolia* subsp. *buxifolia*	single locality-uns rec	4	4					
Proteaceae	*Grevillea linearifolia*	occasional	4	4	4		4		3
Proteaceae	*Grevillea sericea*	occasional	4	4		3,4	3		
Proteaceae	*Grevillea speciosa*	occasional	3,4	3,4	1		4		
Proteaceae	*Hakea dactyloides*	localised-uns rec	4				4		
Proteaceae	*Hakea laevipes*	localised	3,4				3,4		
Proteaceae	*Hakea gibbosa*	occasional	3,4	3,4			4	2	
Proteaceae	*Hakea sericea*	localised	4				3		
Proteaceae	*Hakea teretifolia*	frequent/widespread	3,4	4	1,4		4	2,4	
Proteaceae	*Isopogon anemonifolius*	single locality		3					
Proteaceae	*Lambertia formosa*	occasional	3,4	4	1	4	3,4		
Proteaceae	*Lomatia silaifolia*	occasional	3,4	4	4		3		
Proteaceae	*Persoonia hirsuta*	single locality-uns rec	4						
Proteaceae	*Persoonia lanceolata*	frequent/widespread	3,4	3,4			4	2	3,4
Proteaceae	*Persoonia laurina* subsp. *laurina*	single locality-uns rec	4						
Proteaceae	*Persoonia levis*	frequent/widespread	3,4	4	2	2,3,4	3,4		

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Proteaceae	*Persoonia linearis*	frequent/widespread	3,4	4			3	1	3
Proteaceae	*Petrophile pulchella*	single locality-uns rec	3,4						
Proteaceae	*Xylomelum pyriforme*	single locality-uns rec	3,4						
Ranunculaceae	*Clematis aristata*	occasional	3,4	4		3	3		
Rhamnaceae	*Cryptandra amara*	single locality-uns rec	3,4						
Rhamnaceae	*Cryptandra ericoides*	localised-uns rec	3,4	4					
Rhamnaceae	*Pomaderris ferruginea*	occasional	4	4			3		
Rhamnaceae	*Pomaderris intermedia*	single locality-uns rec		4					
Rubiaceae	*Morinda jasminoides*	single locality-uns rec	3,4						
Rubiaceae	*Opercularia aspera*	occasional	3,4	4			3,4		
Rubiaceae	*Opercularia varia*	localised	4						3
Rutaceae	*Acronychia oblongifolia*	single locality							3
Rutaceae	*Boronia ledifolia*	localised	3,4				4		
Rutaceae	*Boronia parviflora*	single locality-uns rec	4						
Rutaceae	*Boronia serrulata*	single locality-uns rec	3,4						
Rutaceae	*Correa alba*	single locality-uns rec	3,4						
Rutaceae	*Correa reflexa*	frequent/widespread	3,4	4	2	2,3,4	3		
Rutaceae	*Crowea saligna*	frequent/widespread	3,4	4	4	3,4	4	4	3,4
Rutaceae	*Eriostemon australasius*	single locality		4					
Rutaceae	*Philotheca buxifolia* subsp. *buxifolia*	occasional	3,4	3,4		4			3
Rutaceae	*Philotheca buxifolia* subsp. *obovata*	localised-uns rec	4	4					
Rutaceae	*Philotheca salsolifolia*	localised	3,4	1					
Rutaceae	*Zieria laevigata*	localised	3,4	3,4					
Rutaceae	*Zieria pilosa*	occasional	3,4	4		3	4		
Rutaceae	*Zieria smithii*	single locality-uns rec		4					
Santalaceae	*Exocarpos cupressiformis*	occasional	3,4	4			3		3
Sapindaceae	*Dodonaea triquetra*	frequent/widespread	3,4	4	2,4	2,3,4	3		3,4
Scrophulariaceae	*Veronica plebeia*	localised	3,4		4		4		
Sterculiaceae	*Lasiopetalum ferrugineum* var. *ferrugineum*	frequent/widespread	3,4	4	4	4	4		4
Sterculiaceae	*Lasiopetalum rufum*	single locality-uns rec	4						
Sterculiaceae	*Rulingia hermanniifolia*	localised	3,4	3					
Stylidiaceae	*Stylidium graminifolium*	single locality					2		
Stylidiaceae	*Stylidium lineare*	localised	3,4	4					
Thymelaeaceae	*Pimelea curviflora* var. *curviflora*	localised-uns rec	4					4	
Thymelaeaceae	*Pimelea linifolia* subsp. *linifolia*	occasional	3,4	4	2	2,3,4			
Verbenaceae	*Clerodendrum tomentosum*	occasional	4	4					3
Violaceae	*Viola hederacea*	occasional	3,4	4	4	4		4	4
Viscaceae	*Notothixos subaureus*	single locality							2
Vitaceae	*Cissus antarctica*	occasional	3,4	4			4		
Vitaceae	*Cissus hypoglauca*	frequent/widespread	3,4	4		3,4	4		3,4
MONOCOTYLEDONS									
Anthericaceae	*Sowerbaea juncea*	single locality-uns rec	4						
Blandfordiaceae	*Blandfordia nobilis*	single locality-uns rec	3,4						
Centrolepidaceae	*Centrolepis fascicularis*	single locality-uns rec	3,4						
Centrolepidaceae	*Centrolepis strigosa*	localised	3,4			3			
Colchicaceae	*Burchardia umbellata*	single locality-uns rec	3,4						
Commelinaceae	*Commelina cyanea*	frequent/widespread	3,4	4		3,4	4	4	4
Commelinaceae	*Schelhammera undulata*	occasional	3,4	4		3	3		
Cyperaceae	*Baumea acuta*	localised	3,4	4					

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Cyperaceae	*Baumea juncea*	single locality-uns rec	3,4						
Cyperaceae	*Baumea teretifolia*	localised-uns rec	4	4					
Cyperaceae	*Carex appressa*	single locality-uns rec	4						
Cyperaceae	*Caustis flexuosa*	localised	3,4	1,4					
Cyperaceae	*Caustis pentandra*	occasional	3,4	4	4				
Cyperaceae	*Caustis recurvata*	localised	4	4					
Cyperaceae	*Chorizandra sphaerocephala*	single locality-uns rec	3,4						
Cyperaceae	*Cyathochaeta diandra*	single locality-uns rec	3,4						
Cyperaceae	*Cyperus polystachyos*	occasional	3,4	3,4					3
Cyperaceae	*Ficinia nodosa*	frequent/widespread	3,4	4		4	4	2,4	3
Cyperaceae	*Gahnia clarkei*	occasional	3,4	4		4	3,4		
Cyperaceae	*Gahnia sieberiana*	occasional	3,4	4	4				
Cyperaceae	*Gymnoschoenus sphaerocephalus*	single locality-uns rec	4						
Cyperaceae	*Isolepis inundata*	single locality-uns rec	3,4						
Cyperaceae	*Lepidosperma concavum*	occasional	4	4		3,4	3,4		
Cyperaceae	*Lepidosperma filiforme*	localised	3,4	4					
Cyperaceae	*Lepidosperma laterale*	occasional	3,4	4			4		
Cyperaceae	*Lepidosperma neesii*	single locality-uns rec	3,4						
Cyperaceae	*Lepidosperma viscidum*	single locality-uns rec	3,4						
Cyperaceae	*Ptilothrix deusta*	localised	3,4	3,4					
Cyperaceae	*Schoenus apogon*	single locality-uns rec	3,4						
Cyperaceae	*Schoenus brevifolius*	single locality-uns rec	3,4						
Cyperaceae	*Schoenus ericetorum*	single locality-uns rec	4						
Cyperaceae	*Schoenus imberbis*	localised	3,4	4					
Cyperaceae	*Tricostularia pauciflora*	single locality	3,4						
Eriocaulaceae	*Eriocaulon scariosum*	single locality-uns rec	4						
Haemodoraceae	*Haemodorum corymbosum*	single locality-uns rec		4					
Haemodoraceae	*Haemodorum planifolium*	localised	3,4			3			
Iridaceae	*Patersonia glabrata*	localised	3,4	4					
Iridaceae	*Patersonia sericea*	occasional	3,4	4		3			
Juncaceae	*Juncus continuus*	occasional	3,4	4			3		
Juncaceae	*Juncus planifolius*	single locality-uns rec	3,4						
Juncaceae	*Juncus prismatocarpus*	single locality-uns rec	4						
Juncaceae	*Juncus usitatus*	occasional	3,4		4		3		
Lomandraceae	*Lomandra cylindrica*	occasional	4	4		3	3		
Lomandraceae	*Lomandra filiformis* subsp. *filiformis*	occasional	3,4	4		3,4			
Lomandraceae	*Lomandra glauca*	localised	3,4	4					
Lomandraceae	*Lomandra gracilis*	single locality-uns rec	4						
Lomandraceae	*Lomandra longifolia*	frequent/widespread	3,4	4	4	3,4	3,4	4	3,4
Lomandraceae	*Lomandra obliqua*	frequent/widespread	4	4	2	2,3,4	4		
Orchidaceae	*Acianthus fornicatus*	localised	3,4			3			
Orchidaceae	*Caladenia catenata*	single locality-uns rec		4					
Orchidaceae	*Caleana major*	single locality-uns rec	4						
Orchidaceae	*Calochilus campestris*	single locality				3			
Orchidaceae	*Cryptostylis erecta*	occasional	3,4	4	3				
Orchidaceae	*Cryptostylis subulata*	localised	3,4	4					
Orchidaceae	*Dendrobium linguiforme*	occasional	3,4	4			3		3
Orchidaceae	*Dipodium punctatum*	localised				3	3		
Orchidaceae	*Dipodium roseum*	single locality					2		
Orchidaceae	*Erythrorchis cassythoides*	single locality-uns rec	3						
Orchidaceae	*Orthoceras strictum*	localised	3,4		2				
Orchidaceae	*Prasophyllum sp.*	single locality-uns rec	4						

PLANT GROUP/ Family	Species	Occurrence /single location/ unsubstantiated record	North Head	Dobroyd Head	Middle Head	Chowder Head	Bradleys Head	South Head	Nielsen Park
Orchidaceae	*Pterostylis curta*	single locality			3				
Orchidaceae	*Pterostylis nutans*	occasional			3	3	4		4
Orchidaceae	*Thelymitra ixioides* var. *ixioides*	single locality-uns rec	4						
Philesiaceae	*Eustrephus latifolius*	frequent/widespread	3,4	4	3,4	3,4	4		3
Philesiaceae	*Geitonoplesium cymosum*	frequent/widespread	3,4	4	4		4		3
Philydraceae	*Philydrum lanuginosum*	single locality-uns rec	4						
Phormiaceae	*Dianella caerulea* var. *assera*	single locality							3,4
Phormiaceae	*Dianella caerulea* var. *caerulea*	localised	4		2				
Phormiaceae	*Dianella caerulea* var. *producta*	localised	4	4					
Phormiaceae	*Dianella revoluta*	occasional	3,4			3,4			3
Phormiaceae	*Dianella caerulea*	frequent/widespread	3,4	4	4	3,4	3,4		3
Phormiaceae	*Thelionema caespitosum*	single locality-uns rec	3,4						
Phormiaceae	*Thelionema umbellatum*	single locality-uns rec	3,4						
Poaceae	*Anisopogon avenaceus*	occasional	3,4	4		3			
Poaceae	*Austrodanthonia tenuior*	occasional	4	4		3			
Poaceae	*Austrostipa pubescens*	single locality			3				
Poaceae	*Dichelachne crinita*	single locality-uns rec	4						
Poaceae	*Dichelachne micrantha*	single locality-uns rec	3,4						
Poaceae	*Digitaria didactyla*	single locality-uns rec	3,4						
Poaceae	*Digitaria parviflora*	occasional	4	4		3,4		2	
Poaceae	*Echinopogon caespitosus*	occasional	4	4	2		4		4
Poaceae	*Entolasia marginata*	occasional	3,4	4		3,4			
Poaceae	*Entolasia stricta*	occasional	3,4	4	4		3		
Poaceae	*Eragrostis brownii*	single locality-uns rec	3,4						
Poaceae	*Eragrostis sororia*	single locality				2			
Poaceae	*Hemarthria uncinata* var. *uncinata*	single locality-uns rec	3,4						
Poaceae	*Imperata cylindrica* var. *major*	frequent/widespread	3,4	4	4	3,4	3,4	4	3
Poaceae	*Lachnagrostis aemula*	single locality			4				
Poaceae	*Lachnagrostis filiformis*	localised	4		4				
Poaceae	*Leersia hexandra*	single locality-S limit			1				
Poaceae	*Microlaena stipoides* var. *stipoides*	occasional	4	4	4				4
Poaceae	*Oplismenus aemulus*	localised	3,4						3,4
Poaceae	*Oplismenus imbecillis*	localised	3,4	4			4		
Poaceae	*Panicum simile*	localised	3,4	4					
Poaceae	*Poa affinis*	occasional	3,4			3			
Poaceae	*Spinifex sericeus*	single locality-uns rec	4						
Poaceae	*Sporobolus virginicus*	localised	4	4					
Poaceae	*Themeda australis*	frequent/widespread	3,4	2,4	2	2,3,4	3,4	4	3
Restionaceae	*Baloskion tetraphyllum* subsp. *meiostachyum*	single locality-uns rec	3,4						
Restionaceae	*Chordifex dimorphus*	single locality-uns rec	3,4						
Restionaceae	*Chordifex fastigiatus*	localised	3,4	3,4					
Restionaceae	*Empodisma minus*	localised	3,4						3
Restionaceae	*Eurychorda complanata*	single locality-uns rec	3,4						
Restionaceae	*Hypolaena fastigiata*	single locality-uns rec	3,4						
Restionaceae	*Leptocarpus tenax*	single locality-uns rec	3,4						
Restionaceae	*Lepyrodia scariosa*	localised	3,4	4		4	4		
Smilacaceae	*Smilax glyciphylla*	frequent/widespread	3,4	4	4	3,4	4		3,4
Typhaceae	*Typha orientalis*	single locality-uns rec	3,4						
Xanthorrhoeaceae	*Xanthorrhoea arborea*	occasional	3,4	4		3,4	3,4		
Xanthorrhoeaceae	*Xanthorrhoea media*	localised	3,4				3,4		
Xanthorrhoeaceae	*Xanthorrhoea resinosa*	localised	3,4	4					
Xyridaceae	*Xyris operculata*	single locality-uns rec	3,4						

Appendix 2. Plant species for which there is currently no substantiated record, nor any historical record, but could be regarded as native to Sydney Harbour National Park (i.e. added to Appendix 1) if confirmed with a specimen evidently from a naturally-occurring population

Species	Family	Precinct
FERNS		
Christella dentata	Thelypteridaceae	NH,DH
Hypolepis muelleri	fern	NH
Pellaea falcata	Adiantaceae	NH
Platycerium bifurcatum	Polypodiaceae	NH
Pteris umbrosa	Pteridaceae	NH
DICOTYLEDONS		
Acacia binervata	Fabaceae	NH
Acacia binervia	Fabaceae	NH
Acacia brownii	Fabaceae	NH
Acacia floribunda	Fabaceae	NH,DH
Acacia irrorata	Fabaceae	NH
Acacia longissima	Fabaceae	NH,DH
Angophora floribunda	Myrtaceae	BH
Backhousia myrtifolia	Myrtaceae	DH
Bauera capitata	Cunoniaceae	DH
Callistemon salignus	Myrtaceae	NH
Carpobrotus glaucescens	Aizoaceae	NH
Cayratia clematidea	Vitaceae	DH
Clematis glycinoides var. *glycinoides*	Ranunculaceae	NH,DH
Coronidium elatum	Asteraceae	NH
Crowea exalata	Rutaceae	NH
Cupaniopsis anacardioides	sapindaceae	NP
Cuscuta australis	Convolvulaceae	NH
Dillwynia glaberrima	Fabaceae	NH,DH
Drosera pygmaea	Droseraceae	NH
Eucalyptus multicaulis	Myrtaceae	NH
Gompholobium minus	Fabaceae	NH
Grevillea mucronulata	Proteaceae	NH
Hakea salicifolia	Proteaceae	DH
Hibbertia asterotricha	Dilleniaceae	BH
Hibbertia cistiflora subsp. *cistiflora*	Dilleniaceae	NH
Hibbertia diffusa	Dilleniaceae	NH
Hibbertia serpyllifolia	Dilleniaceae	DH
Hibbertia stricta	Dilleniaceae	NH
Hydrocotyle tripartita	Apiaceae	DH
Leptospermum grandifolium	Myrtaceae	MH
Leucopogon juniperinus	Ericaceae	NH
Lissanthe strigosa	Ericaceae	NH
Marsdenia rostrata	Apocynaceae	NP
Melaleuca styphelioides	Myrtaceae	BH
Micrantheum hexandrum	Euphorbiaceae	NH,DH
Opercularia diphylla	Rubiaceae	NH
Opercularia hispida	Rubiaceae	NP
Persoonia mollis	Proteaceae	BH
Petrophile sessilis	Proteaceae	NH
Philotheca buxifolia	Rutaceae	DH
Podolobium ilicifolium	Fabaceae	MH
Polyscias elegans	Araliaceae	NP
Pomaderris discolor	Rhamnaceae	BH
Pseuderanthemum variabile	Acanthaceae	CH
Pseudognaphalium luteoalbum	Asteraceae	NH
Pultenaea ferruginea	Fabaceae	NH
Pultenaea hispidula	Fabaceae	DH
Pultenaea scabra	Fabaceae	NH
Rubus moluccanus var. trilobus	Rosaceae	NH
Stackhousia spathulata	Stackhousiaceae	NH
Syzygium australe	Myrtaceae	DH
Tasmannia insipida	winteraceae	MH
Telopea speciosissima	Proteaceae	BH
Tetratheca neglecta	tremandraceae	NP
Trema tomentosa var. *viridis*	Ulmaceae	DH
Tristaniopsis laurina	Myrtaceae	DH
Wikstroemia indica	Thymelaeaceae	NH
Wilkiea huegeliana	Monimiaceae	DH
MONOCOTYLEDONS		
Caesia parviflora var. *parviflora*	Anthericaceae	DH
Carex breviculmis	Cyperaceae	NH
Chiloglottis trapeziformis	Orchidaceae	NH
Chloris acicularis	Poaceae	NH
Chorizandra cymbaria	Cyperaceae	NH
Crinum pedunculatum	Amaryllidaceae	DH
Cymbidium suave	Orchidaceae	BH
Dendrobium speciosum	Orchidaceae	NP
Dianella congesta	Phormiaceae	DH
Eleocharis sphacelata	Cyperaceae	NH
Gahnia aspera	Cyperaceae	NH
Gahnia erythrocarpa	Cyperaceae	NH,DH
Gahnia melanocarpa	Cyperaceae	NH
Gahnia radula	Cyperaceae	DH
Lepidosperma flexuosum	Cyperaceae	NH
Lepidosperma limicola	Cyperaceae	NH
Lepidosperma squamatum	Cyperaceae	NH
Lomandra brevis	Lomandraceae	DH
Lomandra multiflora subsp. *multiflora*	Lomandraceae	DH
Microtis rara	Orchidaceae	MH
Notodanthonia longifolia	Poaceae	NH
Paspalidium distans	Poaceae	NH,BH
Patersonia fragilis	Iridaceae	NH
Plinthanthesis paradoxa	Poaceae	NH
Poa labillardierei	Poaceae	MH
Sacciolepis indica	Poaceae	NH
Schoenus paludosus	Cyperaceae	NH
Tetraria capillaris	Cyperaceae	NH
Tricoryne elatior	Anthericaceae	NH
Typha domingensis	Typhaceae	NH
Xanthorrhoea concava	Xanthorrhoeaceae	NH
Xyris gracilis	Xyridaceae	NH

Appendix 3. Potential weed species: Non-local native species that are becoming naturalised or have been planted in Sydney Harbour National Park

Species	Family	Precinct	Native to Sydney Harbour NP
Ferns			
Cyathea cooperi	Cyatheaceae	DH	non-local native becoming weed
Nephrolepis cordifolia	Davalliaceae	NH,DH	non-local native becoming weed
Dicotyledons			
Acacia baileyana	Fabaceae		non-local native becoming weed
Acacia pycnantha	Fabaceae		non-local native becoming weed
Castanospermum australe	Fabaceae	DH	non-local native, probably planted
Corymbia eximia	Myrtaceae	NH	non-local native, probably planted
Ficus macrophylla	Moraceae		non-local native becoming weed
Grevillea longifolia	Proteaceae	DH	non-local native, probably planted
Lophostemon confertus	Myrtaceae	NH,DH	non-local native becoming weed
Melia azedarach	Meliaceae	NH	non-local native, probably bird-dispersed
Eucalyptus saligna	Myrtaceae	DH	local native but probably planted
Monocotyledons			
Archontophoenix cunninghamiana	Arecaceae	DH	non-local native, probably planted or bird-dispersed
Doryanthes excelsa	Doryanthaceae	DH	non-local native, probably planted
Cynodon dactylon	Poaceae	DH	exotic, invasive weed
Livistona australis	Arecaceae	DH,BH	local native but probably planted

Plant species first recognised as naturalised or naturalising for New South Wales in 2004 and 2005

John R. Hosking[1], Barry J. Conn[2], Brendan J. Lepschi[3] and Clive H. Barker[4]

[1]Industry & Investment New South Wales, 4 Marsden Park Road, Calala, NSW 2340,
Australia; john.hosking@industry.nsw.gov.au
[2]National Herbarium of New South Wales, Royal Botanic Gardens, Sydney, NSW 2000, Australia;
Barry.Conn@rbgsyd.nsw.gov.au
[3]Australian National Herbarium, Centre for Plant Biodiversity Research, GPO Box 1600, Canberra, ACT 2601, Australia;
Brendan.Lepschi@csiro.au
[4]28 Wallis Street, Lawson, NSW 2783, Australia: ozbundu@hotmail.com

Abstract: Information is provided on the taxonomy and distribution of 62 taxa of naturalised or naturalising plants newly recorded for the state of New South Wales during the period 1 January 2004 and 31 December 2005 and 1 species treated in the 2002 revised *Flora of New South Wales* Volume 2 but overlooked in an earlier paper of this series. Of these taxa, 17 are new records for Australia (prefaced with a †). The 62 taxa are: *Acer palmatum*, †*Acer saccharinum*, *Achillea filipendulina*, *Acokanthera oblongifolia*, †*Anemone hupehensis* var. *japonica*, *Berberis aquifolium*, †*Bidens aurea*, †*Brugmansia suaveolens*, *Brugmansia* x *candida*, *Buddleja dysophylla*, †*Convolvulus farinosus*, *Cordyline australis*, *Coriandrum sativum*, *Corymbia citriodora* (Australian species naturalised outside its native range), *Crassula ericoides* subsp. *ericoides*, *Crotalaria retusa* (Australian species naturalised outside its native range), *Cyperus prolifer*, *Echinochloa polystachya*, *Ficus carica*, †*Gladiolus dalenii*, †*Gladiolus* cultivar, *Hakea laurina* (Western Australian species), *Hemerocallis fulva* var. *fulva*, *Hieracium pilosella*, *Hydrangea macrophylla*, *Hydrocleys nymphoides*, *Hymenachne amplexicaulis*, *Hypericum calycinum*, *Impatiens balfouri*, *Indigofera spicata*, *Iris laevigata*, †*Juglans ailantifolia*, *Lilium lancifolium*, *Lygodium japonicum*, *Malephora crocea*, *Mauranthemum paludosum*, *Melastoma malabathricum*, †*Nassella tenuissima*, *Pelargonium quercifolium*, †*Phoenix reclinata*, *Phormium tenax*, *Pinus contorta*, *Podranea ricasoliana*, †*Polygonatum* x *hybridum*, *Polypremum procumbens*, †*Primula malacoides*, *Rhaphiolepis umbellata*, *Romneya coulteri*, *Romneya trichocalyx*, *Setaria incrassata*, †*Sideritis lanata*, †*Sorbus aucuparia*, *Spartium junceum*, *Stylosanthes guianensis*, *Stylosanthes humilis*, †*Symphoricarpos albus* var. *laevigatus*, *Syzygium paniculatum* (Australian species naturalising outside its native range), *Tibouchina urvilleana*, †*Tradescantia cerinthoides*, †*Utricularia sandersonii*, *Washingtonia filifera* and *Zephyranthes carinata*. The overlooked species is *Eugenia uniflora*.

Appendix 1 summarises information on the 174 species covered in this paper or the two previous papers in the series (Hosking et al. 2003, Hosking et al. 2007).

Cunninghamia **(2011) 12 (1) : 85–114**

Introduction

This paper is part of a series covering taxa recognised as naturalised or naturalising by the National Herbarium of New South Wales (standard code for this herbarium, NSW, is used throughout this paper). Earlier papers covered the periods 2000–2001 and 2002–2003 (Hosking et al. 2003, Hosking et al. 2007). This paper draws attention to a number of new naturalisations recorded for the state of New South Wales (N.S.W.) and the Australian Capital Territory (ACT) over the period 2004–2005 and follows the format of Hosking et al. (2007). Only taxa considered to be spreading from initial plantings or other naturalisations (e.g. from discarded garden refuse) are covered. 'Naturalised' in this paper refers to non-native taxa that have been reproducing (sexually or vegetatively) in the wild for at least one generation. 'Naturalising' covers taxa growing in the wild that have not yet reproduced, or are not spreading vegetatively.

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Methods

All taxa treated are represented by vouchers lodged at NSW or the Australian National Herbarium, Canberra (CANB). A number of taxa listed were first collected prior to 2004 but are included here as these records were overlooked for *Flora of New South Wales* accounts, or in our earlier accounts, and were subsequently noted during 2004 or 2005. Following recent collections a few old specimens stored at the end of genera and families in the NSW collection were able to be determined to species. There are also likely to be other records of recently naturalised species collected in the area during 2004 and 2005 that are housed at other Australian herbaria and we urge collectors in other states to lodge material collected from the Australian Capital Territory or New South Wales at either CANB or NSW.

The *Germplasm Resources Information Network database* (USDA) (URL http://www.ars-grin.gov/cgi-bin/npgs/html/taxgenform.pl) and *The International Plant Name Index* (http://www.ipni.org/index.html) were extensively consulted to determine currently accepted names, authorities and native range of taxa covered in this paper. The *PlantNET* website (NSW) (http://plantnet.rbgsyd.nsw.gov.au/) was used to determine the current status of knowledge of introduced plants in New South Wales (PlantNET 1999+). The *NSW Collections* (NSW) and *Australian National Herbarium Specimen Information Records* (CANB) databases, together with the *Australia's Virtual Herbarium* website (http://www.ersa.edu.au/avh/) were extensively used to determine the known records of introduced taxa.

Taxon names used are those currently adopted by NSW and can be viewed in PlantNET (1999+). Nomenclatural details were checked in APNI (1993+). Herbarium codes follow Holmgren et al. (1990).

Information on means of dispersal of various taxa treated in this paper is given under 'Notes' for each taxon where this is known. Where the dispersal mechanism is not listed, the taxon concerned is presumed to spread by seed. However, the actual means of dispersal is not known for a number of taxa treated.

Discussion

The definition of the term 'naturalised' as used in this paper is outlined above. Given that there is a degree of disagreement as to how this term should be applied (see Richardson et al. 2000, Pyšek et al. 2004), we have provided additional information on numbers of plants present, area covered and reproductive status of all taxa treated in this paper to allow for these differences in interpretation.

There are many ways of detecting new plant naturalisations (Hosking et al. 2001). The records of plant naturalisations in N.S.W. listed below are the result of (i) collections made by experts who have a reasonable knowledge of local floras, including local government weeds officers, environmental consultants, bush regenerators, professional botanists and staff from Landcare and Greening Australia and (ii) specimens retained by herbaria who provide plant identifications for the general public, government agencies and other professionals.

It is hoped that publication of new records of plant species naturalised in N.S.W. will prompt further collections of introduced species. In the long term, this approach will focus attention on potential problem species, and hopefully lead to their eradication before they have the opportunity to spread and become serious weeds.

Appendix 1 summarises information on the 174 species in this paper or in the two previous papers in the series (Hosking et al. 2003, Hosking et al. 2007). Name, Family, Growth Form, First Record, Botanical Regions, Place of Origin, Introduction Source, Weed Potential in NSW, and *Cunninghamia* volume are provided.

Plant species first recognised as naturalised in New South Wales during 2004 and 2005

The following taxa are grouped as follows: Ferns, Conifers and allies, Monocotyledons and Dicotyledons, then listed in alphabetical order by family (based on the *Angiosperm Phylogeny Website* (http://www.mobot.org/MOBOT/Research/APweb/welcome.html), then by genus and species, followed by vernacular name (where known). This is followed by references to published descriptions (including botanical illustrations and photographs), region of origin, distribution within N.S.W. according to botanical regions, habitat preferences (including areas where the taxon is likely to naturalise based on native range and areas where it has naturalised (if such information can be determined), the first known herbarium record, additional herbarium records for the State and miscellaneous notes (including relative abundance, invasiveness and whether naturalised in other states or overseas). Authorities for native species are those currently recognised at the National Herbarium of New South Wales (NSW).

Ferns

Lygodiaceae

***Lygodium japonicum* Sw.**
Japanese Climbing Fern

DESCRIPTION: Climbing fern. See Chinnock in McCarthy (1998) and Diggs et al. (2006).

REGION OF ORIGIN: Native of Asia from Japan and eastern and southern China to Pakistan, Sri Lanka and Papua New Guinea.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Recorded from bushland.

FIRST RECORD: Below Gnarbo, Kogarah, *M. Monera s.n.*, 4 Aug 2000 (NSW).

NOTES: Spread by movement of spores and locally by rhizomes. Notes with the Kogarah collection are as follows 'In regenerating bushland area, although Lantana and Asparagus present.' There is also a collection made by H. Bower on 20 Apr 2007 on Lot 1 DP 129374 Vallances Road, Mullumbimby but there was no information with regard to whether the collection is from a cultivated or naturalised plant. This species is also naturalised in the Northern Territory and Queensland (Chinnock in McCarthy 1998, Bostock in Bostock & Holland 2007). It is considered to be naturalised and invasive in south eastern USA. (Diggs et al. 2006).

Conifers and allies

Pinaceae

Pinus contorta Douglas ex Loudon
Lodgepole Pine

DESCRIPTION: Pine tree to 27 m high. See Sykes in Webb et al. (1988) and Farjon & Styles (1997).

REGION OF ORIGIN: Native of North America (western Canada, western USA, Mexico (Baja Norte)).

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands, Southern Tablelands. Naturalised near original plantings and likely to spread in Tableland areas of N.S.W. In the Blue Mountains National Park site this pine was growing in an open forest of *Eucalyptus pauciflora* and *Eucalyptus dalrympleana* with *Daviesia latifolia*, *Gahnia aspera*, *Poa sieberiana*, *Deyeuxia gunniana*, *Acacia melanoxylon*, *Babingtonia* sp., *Epacris* sp., *Hypoxis* sp. and a single *Pinus radiata*.

FIRST RECORD: Blue Mountains National Park, Mt Werong Road, 500 m from National Park entrance, *C.H. Barker 41*, 5 Feb 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by wind-dispersed seed, mostly following fire. At the Blue Mountains National Park site there were about 300 naturalised plants of all ages including cone-bearing trees over about 70 m x 50 m. The species is also reported to be naturalised in large numbers in at least one location in the Brindabella Ranges (G. Carr & V. Stajsic pers. comm. Mar 2004). In Kosciusko National Park 60% of the wilding *Pinus* spp. are reported to be *P. contorta* (Williams & Wardle 2009). *Pinus contorta* previously reported from Charlotte Pass (Hill in McCarthy 1998) and listed in Harden & Murray (2000) has been reidentified as *Pinus mugo* Turra. *Pinus contorta* is also recorded as naturalised in Victoria (Walsh & Stajsic 2007). This pine is one of the five most invasive *Pinus* species according to Rejmánek & Richardson (1996). *Pinus contorta* is considered to be the most aggressive naturalised conifer at medium to high altitudes in New Zealand where it has invaded large areas (Sykes in Webb et al. 1988). In New Zealand it was widely planted in montane areas, often via aerial seeding (Sykes in Webb et al. 1988). *Pinus contorta* is also naturalised in Europe, Argentina and Chile (Gaussen et al. in Tutin et al. 1993, Simberloff et al. 2010).

Monocotyledons

Amaryllidaceae (Amaryllidoideae)

Zephyranthes carinata Herb. [*Zephyranthes grandiflora* Lindl. auct.]
Pink Storm Lily, Rain Lily

DESCRIPTION: Herb to 25 cm high. See Hooker (1825), Lindley (1825) and Ji & Meerow in Wu & Raven (2000, 2002).

REGION OF ORIGIN: Native from southern USA to Argentina and to the Caribbean Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Recorded from an area of roadside *Pennisetum clandestinum* near Ballina and a lawn of *Ehrharta erecta* near Boat Harbour.

FIRST RECORD: 8.6 km NNE of Ballina P.O., outside fence of property 'Wylies Way', *R.G. Coveny 12778, Z. Donabauer & C. Dunn*, 19 Oct 1987 (NSW).

ADDITIONAL RECORD: Alongside Gan Gan Road, Boat Harbour, *J.R. Hosking 2542 & G.C. Prichard*, 16 Nov 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. The species was recorded as occasional in a road verge near Ballina and 33 flowering plants were recorded from a mown open area near Boat Harbour. *Zephyranthes carinata* is also naturalised in Queensland (Forster in Bostock & Holland 2007) as well as South Africa and China (Reid & Archer in Arnold & de Wet 1993, Ji & Meerow in Wu & Raven 2000).

Arecaceae

Phoenix reclinata Jacq.
Senegal Palm

DESCRIPTION: Palm to 12 m high. See Barrow (1998) and Zona in Morin (2000).

REGION OF ORIGIN: Native to tropical and subtropical Africa, Asia (southern Saudi Arabia, Yemen) and Indian Ocean islands (Comoro Islands, Madagascar).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Recorded from a wetland at Marmong Point, a suburb of Newcastle.

FIRST RECORD: Wetland over road from Marmong Cove Marina, Marmong Point, *J.R. Hosking 2543 & G.C. Prichard*, 17 Nov 2004 (CANB, MEL, NE, NSW).

NOTES: Fruits are animal-dispersed. At Marmong Point there were many hundreds of plants of all ages growing in an area that is seasonally wet. The species is recorded as often growing in seasonally water-logged or inundated areas but can be found in drier locations (Barrow 1998). In other countries trunks and leaves of this palm are used for building purposes, leaflets for baskets, hats, brushes, building ties, woven dolls and ornaments, fruits are eaten and the sap fermented into an alcoholic beverage (Barrow 1998). This palm is not known to be naturalised elsewhere in Australia but is recorded as naturalised in the USA (Adanson et al. in Morin 2000).

Washingtonia filifera (Linden ex André) H. Wendl.
American Cotton Palm, Cotton Palm, California fan palm.

DESCRIPTION: Palm to 40 m high. See McClintock in Hickman (1993) and Zona in Morin (2000).

REGION OF ORIGIN: Native of Mexico (Baja Norte) and south western USA.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Western Slopes. Recorded from a drain where growing with naturalised exotic species such as *Fraxinus angustifolia*, *Acer negundo*, *Ligustrum sinense* and *Ligustrum lucidum*.

FIRST RECORD: Best Reserve, Ashmont Avenue (opposite Bulolo Street), Ashmont Wagga Wagga, *B. Lepschi 5370*, 10 Nov 2004 (CANB).

NOTES: Spread by seed. Two non-reproductive plants to 1.8 m high were seen in the collection area. The drain where these plants were growing was extensively cleared of all woody vegetation in 2005. The species is believed to have naturalised at other locations but there are no other collections to date. The species is recorded as naturalised in Western Australia and South Australia (FloraBase 1998+, eFlora SA 1999+), as an environmental weed in subsaline areas in Victoria (Carr et al. 1992) and as sparingly naturalised in the Northern Territory (APC 2005+). Overseas the species is recorded as naturalised outside its native range in south western USA (Zona in Morin 2000).

Asparagaceae (Lomandroideae)

***Cordyline australis* (G. Forst.) Endl.**
New Zealand Cabbage Tree, Cabbage Tree, Ti Kouka

DESCRIPTION: Small tree to 12 (rarely to 20) m high. See Moore & Edgar (1970), Salmon (1980) and Poole & Adams (1990).

REGION OF ORIGIN: Native of New Zealand.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Growing on clay loam in dry sclerophyll forest below a storm water drain.

FIRST RECORD: Gully in Frank Walford Park (Catalina Park or The Gully), Katoomba, *C.H. Barker 71*, 26 Nov 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed or as a result of dumping of garden waste. Five stems were present in the collection area. The species occurs sporadically in the upper Blue Mountains. *Cordyline australis* is also naturalised in Victoria and Tasmania (Walsh & Stajsic 2007, Buchanan 2009) and listed as doubtfully established in South Australia (eFlora SA 1999+). In Victoria it is naturalised in wet areas (Carr et al. 1992). A *Cordyline* sp., probably *C. australis*, is reported to have naturalised in California (Jepson Online Interchange 2006+).

Asparagaceae (Nolinoideae)

***Polygonatum* x *hybridum* Brügger**
Sólomon's Seal, Garden Solomon's Seal

DESCRIPTION: Herb to at least 90 cm high. See Healy & Edgar (1980) and Stace (1997).

REGION OF ORIGIN: Derived in cultivation.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Recorded from natural bush where it was growing in dark brown loam high in organic matter and with leaf litter to 10 cm thick.

FIRST RECORD: Blue Mountains National Park, adjacent to last house on Cliff Drive, directly north of the Three Sisters, South Katoomba, *C.H. Barker 68*, 30 Oct 2004 (CANB, MEL, NE, NSW).

NOTES: Appears to be spreading vegetatively and/or by movement of tubers. Notes with the specimen indicate that it was growing in natural bushland not far from a house with the same plant in the backyard, that possibly all stems are connected underground and that the patch now occupies about 1.8 m x 1.8 m. This species has not been recorded as naturalised elsewhere in Australia. This hybrid, developed in cultivation, is also naturalised in Europe and New Zealand (DeFilipps in Tutin et al. 1980, Healy & Edgar 1980).

Commeliniaceae

***Tradescantia cerinthoides* Kunth [syn. *Tradescantia blossfeldiana* Mildbr.]**
Spiderwort, Moss Inch Plant

DESCRIPTION: Herb to 30 cm high. See Hunt in Eggli (2001) and Spencer (2005).

REGION OF ORIGIN: Native of south eastern Brazil.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Recorded from rock crevasses and rock shelves in Blaxland.

FIRST RECORD: Rock crevasses below and alongside 58 Ross Crescent near start of track to Florabella Pass, Blaxland, *J.R. Hosking 2446 & C.H. Barker*, 8 Feb 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by movement of plant pieces. There were hundreds of naturalised plants occurring on rock ledges and at the base of a small cliff at Blaxland. This *Tradescantia* is listed as doubtfully established in South Australia (Barker et al. 2005) and as naturalised in New Zealand (P. Heenan pers. comm. 21 Aug 2009). *Tradescantia cerinthoides* is not as invasive as *Tradescantia fluminensis* Vell. (Burns 2004, Burns & Winn 2006).

Cyperaceae

***Cyperus prolifer* Lam.**
Dwarf Papyrus

DESCRIPTION: Sedge to 1.1 m high. See Haines & Lye (1983).

REGION OF ORIGIN: Native of Africa (Kenya, Tanzania, Mozambique, South Africa), Madagascar and the Mascarene Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Known from moist areas, such as a shallow dam and *Melaleuca* swamps. In other countries this sedge is recorded from swamp-edges, stream-sides, and in seasonally flooded habitats (Haines & Lye 1983). This is also likely to be the case in N.S.W.

FIRST RECORD: Boambee, A. Floyd's residence, *A.G. Floyd 1386*, 28 Oct 1979 (CFSHB, NE).

ADDITIONAL RECORDS: Near corner of Cudgen Street and Booyun Street, Brunswick Heads, *P.G. Kodela 26*, 29 Oct 1990 (BRI, NE, UNSW, NSW); Cudgen Lake near Bogangar, *A.R. Bean 14544*, 23 Jan 1999 (BRI, NSW); Behind houses on Salamander Way, Sandpiper Reserve, Salamander Bay, *J.R. Hosking 2536 & G.C. Prichard*, 16 Nov 2004 (CANB, MEL, NSW, NE).

NOTES: Spreads by daughter plants that grow in the inflorescence; as shoots become heavier stems lean over and on reaching the ground daughter plants attach and grow. The earliest record lists over 100 plants and states 'Becomes a pest due to prolific rooting of inflorescences'. Plants were present in sizeable clumps at Cudgen Lake and in Sandpiper Reserve. Notes on a specimen collected by N. Romanowski and housed at NSW suggest that plants are sold under a number of names including *Cyperus haspan* in the nursery trade in Australia and *Cyperus isocladus* in the USA. Plants are also sold as *Cyperus papyrus* cultivar Nana in the nursery trade in Australia (G. Prichard pers. comm. Nov 2004). This species is also naturalised in Queensland and Florida (Booth in Bostock & Holland 2007, Wunderlin & Hansen 1996+).

Iridaceae

Gladiolus dalenii Van Geel. [syn. *Gladiolus natalensis* Reinw. ex Hook. nom. illeg.]

Natal Lily, Dragon's Head Lily

DESCRIPTION: Herb to 1.5 (rarely to 2) m high. See Goldblatt & Manning (1998) and Goldblatt in Morin (2002).

REGION OF ORIGIN: Native of Africa (Senegal to Sudan, Eritrea and South Africa) and Asia (Saudi Arabia, Yemen).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast, Central Tablelands and Central Coast. Widely naturalised on sandy soils in the Blue Mountains and at Port Stephens.

FIRST RECORD: Road reserve at end of Armstrong Road above Jamison Creek, Wentworth Falls, *C.H. Barker 32*, 11 Jan 2004 (CANB, MEL, MO, NE, NSW).

ADDITIONAL RECORDS: Southern side of Great Western Highway, western edge of Bullaburra, *C.H. Barker 36*, 21 Jan 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed and discarded bulbs. This species has been planted as an ornamental in many locations in N.S.W. Naturalised plants are scattered from the Cumberland Plain to the upper Blue Mountains, and in the Port Stephens area. It is probably much more widely naturalised. *Gladiolus dalenii* is recorded as doubtfully naturalised in South Australia (Barker et al. 2005) and naturalised in New Zealand and the USA (Healy & Edgar 1980, Goldblatt in Morin 2002).

Gladiolus cultivar (with *Gladiolus dalenii* strain dominating)

DESCRIPTION: Herb to 1.5 (rarely to 2) m high.

REGION OF ORIGIN: Cultivar of garden origin.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Naturalised on sandy soils in the Blue Mountains.

FIRST RECORD: End of small dirt road, North Street, North Katoomba, *C.H. Barker 37*, 22 Jan 2004 (CANB, MO, NSW).

ADDITIONAL RECORD: Between cemetery and North Road, North Katoomba, *C.H. Barker 38*, 22 Jan 2004 (NSW).

NOTES: Spread by seed and discarded bulbs. Plants are found scattered in the upper Blue Mountains. This *Gladiolus* cultivar is not known to be naturalised in other states or overseas.

Iris laevigata Fisch.

Rabbitear Iris

DESCRIPTION: Herb to 60 cm high. See Mathew (1981) and Zhao et al in Wu & Raven (2000, 2002).

REGION OF ORIGIN: Native of China (Heilongjiang, Jilin, Liaoning, Yunnan), Japan, Korea and the Russian Federation (Amur, eastern Siberia, Khabarovsk, Magadan, Primorye).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Invading the edge of a swamp.

FIRST RECORD: Behind houses on Salamander Way, Sandpiper Reserve, Salamander Bay, *J.R. Hosking 2537 & G.C. Prichard*, 16 Nov 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. Hundreds of plants occurred in the collection area where they appeared to be spreading from cultivated plants. In its native range the species occurs in swamps and on lake margins (Mathew

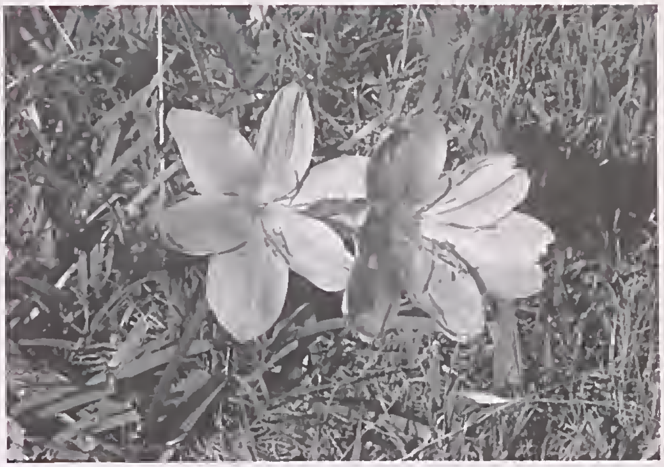

Fig. 1. *Zephyranthes carinata* growing on sandy soil in a mown area at Boat Harbour.

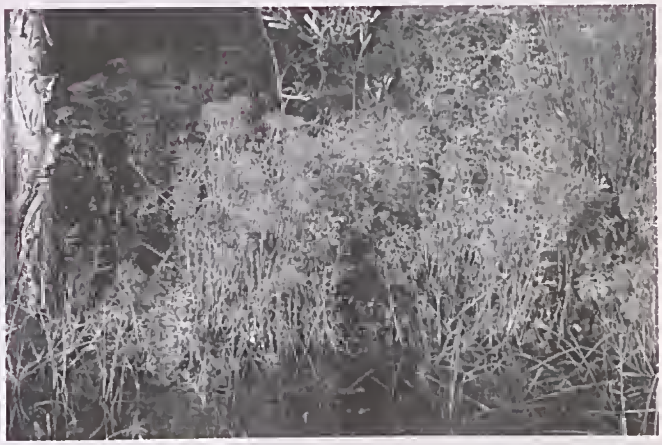

Fig. 2. *Cyperus prolifer* growing in a *Melaleuca* swamp at Salamander Bay.

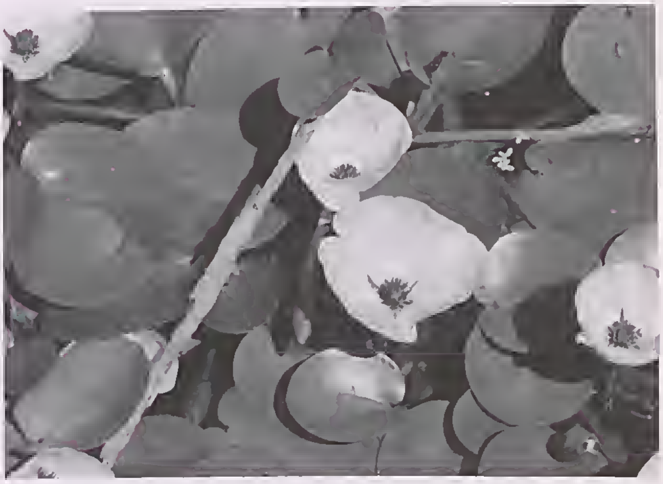

Fig. 3. *Hydrocleys nymphoides* has attractive yellow petals and can form dense mats on slow flowing water.

1981). *Iris laevigata* is also naturalised in Western Australia (Keighery 2005) and the USA (USDA, NRCS 1995+), and has been collected in the wild in New Zealand (Healy & Edgar 1980).

Liliaceae

Lilium lancifolium Thunb. [_Lilium tigrinum_ Ker Gawl.]
Tiger Lily

DESCRIPTION: Lily to 2 m high. See Liang & Minoru in Wu & Raven (2000, 2002) and Skinner in Morin (2002).

REGION OF ORIGIN: Native of China (Anhui, Gansu, Guangxi, Hebei, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Qinghai, Shaanxi, Shandong, Shanxi, Sichuan, Xizang, Zhejiang), Korea and Japan.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Recorded growing in sandy soil in an open *Eucalyptus* spp. forest.

FIRST RECORD: Eastern side of Katoomba Cemetery, North Katoomba, *J.R. Hosking 2441 & C.H. Barker*, 7 Feb 2004 (CANB, NSW).

NOTES: Spread by movement of axillary bulbils and bulb scales. In the collection area there was a small clump of 11 naturalised plants to 1.5 m high. In China this lily is widely cultivated for its edible bulbs (Liang & Minoru in Wu & Raven 2000). In Victoria the species is listed by Carr et al. (1992) as being rare or localised in small populations in damp sclerophyll forest, but there are no herbarium specimens to back up this statement at present. *Lilium lancifolium* is naturalised near habitation in eastern and north eastern USA (Skinner in Morin 2002) and on roadsides and wasteplaces in New Zealand (Healy & Edgar 1980).

Limnocharitaceae

Hydrocleys nymphoides (Humb. & Bonpl. ex Willd.) Buchenau
Water Poppy

DESCRIPTION: Water plant with floating leaves. See Conn in Walsh and Entwisle (1994).

REGION OF ORIGIN: Native of the Americas from Guatemala to Argentina, and to Caribbean Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast, Central Coast and South Western Slopes. Recorded from a slow flowing stream where growing with other water plants such as *Colocasia esculenta*, a water *Iris* and *Vallisneria australis*.

FIRST RECORD: Castle Hill, collector not given, Nov 1957 (NSW).

ADDITIONAL RECORD: Mungabareena Reserve, *T.Harrison TH02/01*, 5 Mar 2002 (NSW); Mungabareena Reserve, about 280 m from the Murray River, East Albury, *J.R. Hosking 3293 & L.K. Pearce*, 20 Dec 2009 (CANB, MEL, NE, NSW).

NOTES: Reproduces by plantlets during autumn and also spreads via plant pieces. The Castle Hill collection contained notes that the species was 'rapidly blocking up our two dams'. In Mungabareena Reserve this species covered an area of about 2 m^2 in 2002 (T. Michael (nee Harrison) pers. comm. Jan 2010). At this time the species was dug out. In 2010 the species was covering around 20 m by 10 m in the same Reserve but about one km downstream of the original collection site. Once again it is proposed that the species be removed, in this case by draining and dredging the infested area and burying material from the site. The species has also been recorded from a dam at Murwillumbah (G. Sainty pers. comm. Dec 1993) so the species has probably naturalised at other locations in N.S.W. *Hydrocleys nymphoides* is an attractive horticultural plant that thrives in nutrient-rich stationary or slow flowing water to 1 m deep. It has also naturalised in a number of locations in Queensland and Victoria. In Victoria it is recorded mainly from farm dams and slow-moving rivers (Conn in Walsh and Entwisle 1994) and on roadsides and wasteplaces in New Zealand (Healy & Edgar 1980).

Poaceae

Echinochloa polystachya (Kunth) Hitch.
Aleman grass

DESCRIPTION: Perennial aquatic grass to 3 m high. See Michael in Morin (2003b) and Jacobs et al. (2008).

REGION OF ORIGIN: Native from Southern USA to Argentina and Uruguay, and to the Caribbean Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Recorded from pastures, creeks and low swampy areas.

FIRST RECORD: 10 km south east of Casino, *R. Ensbey s.n.*, 14 Apr 2004 (NSW).

NOTES: Spread by seed (including deliberate planting as a ponded pasture species) and movement of stolon sections and mats of this species. This species has been introduced to many areas of northern Australia as a ponded pasture grass. The herbarium record of this species for N.S.W. is as an occasional plant occurring over about 1 ha. Boorman (2009) lists the species as occurring in Branch Creek downstream of the Bruxner Highway and at Yorklea, both areas on the north coast of N.S.W. In both areas the species was considered to be invasive and capable of producing massive amounts of biomass. Attempts are being made to eradicate this species at these locations (Boorman 2009). In the aquatic phase plants grow above the fluctuating water level and in the terrestrial phase it forms new shoots from nodes on decaying stems (Griffin et al. 2008). During flooding it sequesters large amounts of nutrients, acting as a nitrogen sink and may cause nitrate and nitrite poisoning in cattle following a drought (Griffin et al. 2008). The species is naturalised in Queensland and the Northern Territory (Simon et al. in Bostock & Holland 2007, Cowie & Kerrigan 2007). This grass replaces native aquatic species. It is also considered to be a weed in the USA, Hawaii, Argentina, Mexico, India and Zaire (Griffin et al. 2008) and naturalised in Chile (Arroyo et al. in Mooney & Hobbs 2000).

Hymenachne amplexicaulis (Rudge) Nees
Olive Hymenachne, Hymenachne

DESCRIPTION: Perennial aquatic grass to 3.5 m high. See Barkworth in Morin (2003b), Jacobs et al. (2008) and Anon. (2003).

REGION OF ORIGIN: Native from Mexico to Uraguay, and to the Caribbean Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Recorded from pastures, creeks and low swampy areas.

FIRST RECORD: 10 km south east of Casino, *R. Ensbey s.n.*, 14 Apr 2004 (NSW).

ADDITIONAL RECORD: Roadside, T.R. [Timber Reserve?] Benns Road, off Marks Lane, about 8.8 km SSW of Casino, *J. Stenzel s.n.*, mid Sep 2009 (CANB, NE, NSW).

NOTES: Spread by seed (including deliberate planting as a ponded pasture species), stem fragments or as a contaminant in stockfeed. This species has been introduced to many areas as a pasture grass. The first record of this species for N.S.W. is as an occasional species occurring over about 1 ha. It is thought to have been deliberately planted at the site. It has been reported from a few other locations (Boorman 2009) but there is only one other collection at Australian herbaria for N.S.W. This was for plants covering about 3 m² in a drain leading from a dam. According to J. Stenzel (pers. comm. Sep 2009) the species is not very aggressive in the Casino area and does not handle frost or grazing in drier areas. In northern Australia this grass thrives in water to 2 m deep in areas with wet and dry cycles, and tolerates deeper water than para grass, *Urochloa mutica*. In more tropical conditions *Hymenachne amplexicaulis* provides high quality feed all year round, even as waterbodies dry during extended periods of no rain. It displaces native species from deeper water and threatens native wetland habitat. In its native range it is considered to be a valuable forage (Diaz et al. 2009). *Hymenachne amplexicaulis* is naturalised in Queensland and the Northern Territory (Simon et al. in Bostock & Holland 2007, Cowie & Kerrigan 2007) and is also naturalised and invasive in Florida (Diaz et al. 2009). As a result of its impact on the environment it has been declared a Weed of National Significance in Australia (Anon. 2003).

Nassella tenuissima (Trin.) Barkworth

Mexican Feather Grass

DESCRIPTION: Perennial grass forming dense tussocks to 0.8 m high. See Everett et al. in Wilson (2009).

REGION OF ORIGIN: Native range disjunct, considered native to southern USA (Texas) and Mexico, and also Argentina and Chile.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Southern Tablelands, North Western Slopes. Grassy open areas around a rebuilt ranger's hut at Bendora Dam (ACT) and in the surrounding forest. In Tamworth it has been recorded as spreading in garden beds and a lawn.

FIRST RECORD: Garden beds and lawn at Peter Pan Pre-school Kindergarten, 24 Larool Street, Tamworth, *J.R. Hosking 2513 & A.J. Lawler*, 29 Sep 2004 (BRI, CANB, MEL, NE, NSW).

ADDITIONAL RECORD: Namadgi National Park: next to Bendora House at Bendora Dam, *S. Taylor s.n.*, Feb 2008 (AD, BRI, MEL, MO, NSW).

NOTES: Spread by seed. The collection from Tamworth was from 60 plants growing in garden beds and six plants in the lawn. Only three plants appear to have been planted. Plants at Tamworth have subsequently been removed and this site and two other locations where the species is known to have been planted in Tamworth are checked regularly with any *N. tenuissima* plants found removed. This species is likely to have been introduced to the Bendora site via contaminated machinery used by contractors rebuilding the Ranger's House following the 2003 Canberra bushfires (S. Taylor pers. comm. 18 May 2010). Five mature seeding tussocks were destroyed in this area in 2008 and seedlings have been removed from the area since that time (S. Taylor pers. comm. 18 May 2010). This grass has been sold in nurseries as elegant spear grass, a name that is normally reserved for the Australian native, *Austrostipa elegantissima*. The species has also been recorded as cultivated (but now hopefully removed) in Victoria, Tasmania and Queensland. *Nassella tenuissima* is a weed in its native range and is considered to be of low palatability. It has escaped from cultivation in New Zealand and has become a weed that is continuing to spread. The species is also naturalised in South Africa and Europe (Henderson 2001, Verloove 2005). For more information on this species and its likely impact in Australia see Jacobs et al. (1998) and McLaren et al. (1999).

Setaria incrassata (Hochst.) Hack.

Purple Pigeon Grass

DESCRIPTION: Grass to 2 m high. See Sharp & Simon (2002) and Jacobs et al. (2008).

REGION OF ORIGIN: Native of Africa (Nigeria to Ethiopia and South Africa).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Western Slopes. Known from pasture and a track on basalt soils.

FIRST RECORD: Inverell area, Harris Seeds client, 14 Feb 1995 (NSW).

ADDITIONAL RECORD: Track on southern boundary of Red Bobs Reserve, about 40 km south west of Gunnedah, *J.R. Hosking 2572*, 9 Jan 2005 (CANB, MEL, NE, NSW).

NOTES: Spreads by seed. Notes supplied with the Inverell collection indicate that plants were occurring naturally in pasture. At Red Bobs Reserve there were >100 clumps (*Hosking 2572*). These plants probably arose from pasture planted elsewhere nearby. In this area *Setaria incrassata* was growing with Bambatsi panic, *Panicum coloratum* var. *makarikariense*. These two species are often planted on heavier textured soils (McDonald 1986). *Setaria incrassata* 'variety' Inverell was selected by the New South Wales Conservation Service and released in 1981 (McDonald 1986). This species is also naturalised in Queensland, the Northern Territory and Western Australia (Sharp & Simon 2002).

Xanthorrhoeaceae (Hemerocallidoideae)

Hemerocallis fulva (L.) L. var. *fulva*

Day-lily, Kwanso

DESCRIPTION: Herb to 1.5 m high with perianth segments doubled. See Makino (1964), Ohwi (1965), Xinqi & Noguchi in Wu & Raven (2000) and Straley & Utech in Morin (2002).

REGION OF ORIGIN: Widely cultivated in Asia, probably native to China and Japan.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands and Central Coast. Occurs in areas alongside streams or swampy locations in the Blue Mountains.

FIRST RECORD: Wentworth Falls, Central Park, Falls Road opposite Parkes Street, *C.H. Barker 35*, 19 Jan 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by rhizomes and movement of rhizomes with soil. Many cultivars of *H. fulva* have been bred including the one with double flowers collected from Wentworth Falls. This is now considered to be part of var. *fulva* but is often referred to as *H. fulva* (L.) L. var. *kwanso* Regel (Xinqi & Noguchi in Wu & Raven 2000, World Checklist of Monocotyledons 2006+). Plants are found scattered from the lower to the upper Blue Mountains. Plants were over about 12 m x 12 m in the Wentworth Falls area. There are also NSW specimens collected by E.J. McBarron on 11 Dec 1965 recording plants that have persisted at an old homestead site at Leumeah near Campbelltown. Variety *kwanso* is a triploid not known from the wild in China but probably originating there (Xinqi & Noguchi in Wu & Raven 2000). *Hemerocallis fulva* is naturalised in Queensland (*Batianoff 0308319* – BRI) and in New Zealand, Europe, Canada and the USA (Healy & Edgar 1980, Webb in Tutin et al. 1980, Straley & Utech in Morin 2002).

Phormium tenax **J.R.Forst. & G.Forst.**
New Zealand Flax

DESCRIPTION: Tall herb with flower spikes to 3.5 m high and with leaves to 3 m long. See Moore & Edgar (1970), Poole & Adams (1990) and Wagner et al. (1999).

REGION OF ORIGIN: Native of New Zealand, Chatham Island and Norfolk Island.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands and Central Coast. Recorded from a partly cleared ridgetop and roadsides in woodland and open forest.

FIRST RECORD: Upper side of Cliff Drive, Katoomba, *C.H. Barker 40*, 1 Feb 2004 (CANB, MEL, NE, NSW).

ADDITIONAL RECORD: About 100 m below South Lawson tip, *J.R. Hosking 2434*, 6 Feb 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed and rhizomes. At the Katoomba site there were five naturalised clumps of plants in the collection area and more plants further up the roadside, while at the South Lawson location there was one plant with fruiting spikes. This species is also known from the wild in Sun Valley in the lower Blue Mountains. It is naturalised in Tasmania (Morris in Curtis & Morris 1994), listed as invasive in seasonal freshwater wetlands in Victoria (Carr et al. 1992) and is listed as questionably established in South Australia (Barker et al. 2005). *Phormium tenax* is also naturalised in Hawaii (Wagner et al. 1999).

Dicotyledons

Aceraceae

Acer palmatum **Thunb.**
Japanese Maple

DESCRIPTION: Tree to 16 m high. See Mitchell (1988), Spencer (2002a), le Hardÿ de Beaulieu (2003) and Xu et al. in Wu et al. (2008).

REGION OF ORIGIN: Native of South Korea and Japan.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Blue Mountains in weedy *Eucalyptus* sp. woodland.

FIRST RECORD: Opposite 11 Myall Avenue, Leura, *C.H. Barker 43*, 31 Mar 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. Seedlings of this species are common in the Blue Mountains but this is the only plant known to have reached the reproductive stage. Apparently most seedlings die at a young age. This could be because the species is susceptible to spring frost, which kills the young shoots (le Hardÿ de Beaulieu 2003). This tree is a popular ornamental of temperate climate gardens in Australia. The species is possibly also naturalised in Victoria (Walsh & Stajsic 2007) and has been recorded as weedy in a garden in South Australia (Robyn Barker pers. comm. 4 Sep 2009). *Acer palmatum* has naturalised in Canada, the USA and New Zealand (USDA, NRCS 1995+, Heenan et al. 1999).

Acer saccharinum **L.**
Silver Maple

DESCRIPTION: Tree to 35 m high. See Mitchell (1988), Spencer (2002a) and le Hardÿ de Beaulieu (2003).

REGION OF ORIGIN: Native from eastern Canada to Guatemala.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Native open forest with some naturalised exotics.

FIRST RECORD: Below northern strategic black line fire trail, Blackheath, *J.R. Hosking 2447 & C.H. Barker*, 9 Feb 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. In the collection area there were four naturalised trees (three in one group and one larger tree further down the gully) to 8 m high. There are no other records of naturalised plants in Australia. *Acer saccharinum* is also naturalised outside its native range in the USA (Hrusa et al. 2002).

Aizoaceae

Malephora crocea **(Jacq.) Schwantes**
Angular Pigface, Crocea Iceplant

DESCRIPTION: Subshrub to 25 cm high. See Ferren et al. (1981), Beck in Morin (2003a) and Cunningham et al. (1981, as *Carpobrotus* sp.).

REGION OF ORIGIN: Native of South Africa (Cape Province).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Western Plains. At Lightning Ridge plants were growing with native herbs and grasses in a disturbed area near habitation. Plants in this area were spreading into less disturbed areas.

FIRST RECORD: Pilliga Wee Waa, *M.B. Welch s.n.*, Sep 1926 (NSW).

ADDITIONAL RECORD: Saltbush Corner, below Bevan's Black Opal & Cactus Nursery, Lightning Ridge, *J.R. Hosking 2494*, 11 Jul 2004 (AD, CANB, MEL, NE, NSW).

NOTES: Spread by seed. At Lightning Ridge there were over 1000 clumps of plants over an area of about 100 m x 20 m with a few plants scattered outside this area. According to Cunningham et al. (1981), where the species is listed as *Carpobrotus* sp., the species is recorded from scattered localities throughout western N.S.W. and is often a major component of the pasture over wide areas. Given these comments it is surprising that there are so few specimens of this species in herbarium collections. This species is also recorded as naturalised in South Australia (eFlora SA 1999+) and in California where it is often grown as a ground cover for landscaping (Ferren et al. 1981, Bleck in Morin 2003a).

Apiaceae

Coriandrum sativum **L.**
Coriander

DESCRIPTION: Herb to 1 m high with a strong odour. See Makino (1964), Stace (1997) and Spencer (2002b).

REGION OF ORIGIN: Possibly native from the Mediterranean region to south-western Asia but native range now obscure.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Western Slopes, North Western Slopes, North Western Plains. Notes with specimens record the species growing in lucerne, faba bean and chickpea or on an irrigation bank after summer crops were removed.

FIRST RECORD: 20 km south of Narromine, *B.G. Bully s.n.*, 22 Jun 2000 (NSW).

ADDITIONAL RECORDS: 30 km SW of Narromine, *Asley s.n.*, 26 Jun 2000 (NSW); 'Glenoak', Bellata, *G. Constance s.n.*, 28 Sep 2001 (NSW); 'Glenkerry', property owned by J.H. & R.S. Tourle, Willow

Tree Road, Quirindi, *A. Robertson s.n.*, 31 Oct 2008 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. Coriander is a widely used spice and crops of this species have been grown in many states in the past. In N.S.W. the species appears to be mainly found in crops of other species so it may be occurring as a seed contaminant rather than a naturalised species. Coriander is also recorded as naturalised in Queensland, South Australia and Western Australia (Bean in Bostock & Holland 2007, Barker et al. 2005, FloraBase 1998+) and as possibly naturalised in Victoria (Walsh & Stajsic 2007). It is also naturalised in many countries outside Australia (Holm et al. 1979, Webb in Webb et al. 1988, Constance in Hickman 1993, Menglan & Watson in Wu & Raven et al. 2005).

Apocynaceae (Rauvolfioideae)

Acokanthera oblongifolia (Hochst.) Codd

Bushman's Poison, Hottentot's-poison, Poison Arrowplant, Wintersweet

DESCRIPTION: Shrub or small tree to 6 m high. See Codd in Dyer et al. (1963) and Spencer (2002b).

REGION OF ORIGIN: Native of South Africa (eastern Cape Province, Natal) and southern Mozambique.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Known from sub tropical rainforest undergoing regeneration at Coocumbac Island and mostly native vegetation on the edge of dunes at Nelson Bay.

FIRST RECORD: Coocumbac Island Nature Reserve, Manning River at Taree, *M. Dodkin s.n.*, May 2003 (BRI).

ADDITIONAL RECORD: Bushland behind beach at the junction of Harwood Avenue and Beach Road, Nelson Bay, *J.R. Hosking 2540 & G.C. Prichard*, 16 Nov 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. On Coocumbac Island there was only a single shrub 50 cm high, while at Nelson Bay plants were growing in two thickets. Probably one plant in each thicket had been planted. It is likely that original plants here were grown as ornamentals as flowers are attractive and sweetly scented. This species is found in coastal bush and woodland not far from the coast in South Africa where the species is often cultivated (Codd in Dyer et al. 1963). Sap of this species is highly toxic (Codd in Dyer et al. 1963). This species is recorded as doubtfully naturalised in Queensland (Forster in Bostock & Holland 2007).

Asteraceae

Achillea filipendulina Lam.

Fern-leaf yarrow

DESCRIPTION: Herb to 1.5 m high. See Spencer (2002b) and Thompson (2007).

REGION OF ORIGIN: Native of Asia (Afghanistan, Armenia, Azerbaijan, Ciscaucasia, Iran, Iraq, Kyrgyzstan, Tajikistan and Turkey).

NEW SOUTH WALES DISTRIBUTION / HABITATS: Southern Tablelands. No habitat information available.

FIRST RECORD: Island Bend dam viewpoint, Snowy Mountains, *M.E. Phillips s.n.*, 8 Feb 1966 (CANB, NSW)

NOTES: Spread by seed. Although collected many years ago the identity of this species was only determined as part of the preparation of Asteraceae for the *Flora of Australia* series. The species has also been collected near Adelaide in South Australia (Thompson 2007). Thompson (2007) did not consider the species to be naturalised. The

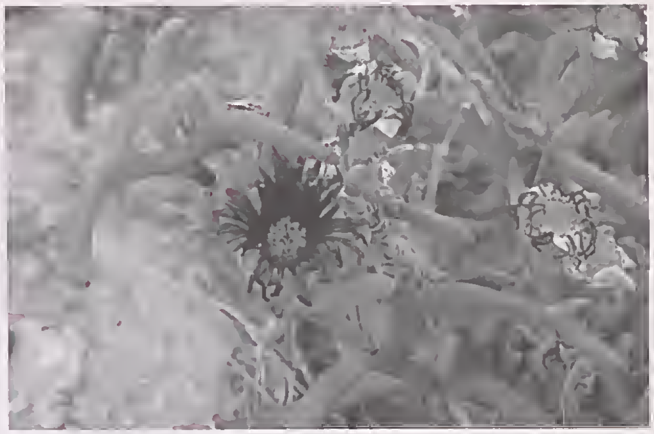

Fig. 4. *Malephora crocea* is a succulent that has naturalised in inland areas of N.S.W.

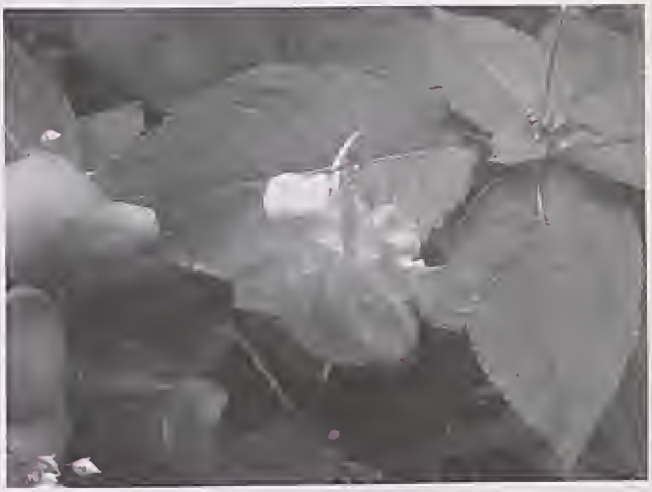

Fig. 5. *Impatiens balfourii* is often grown for its attractive flowers and naturalises in cooler areas of Australia.

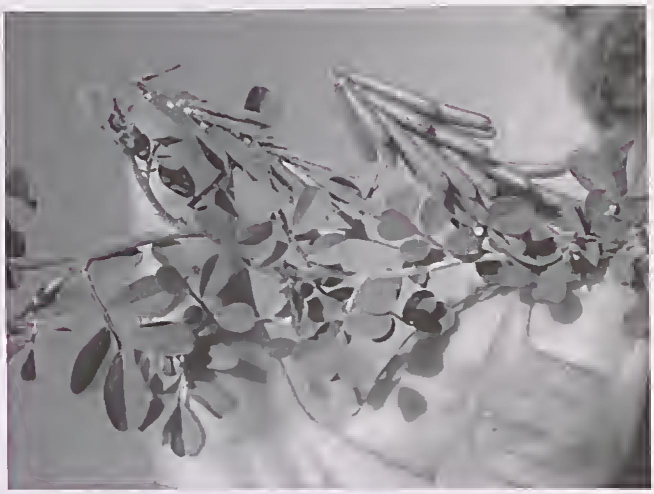

Fig. 6. *Indigofera spicata* is often found growing in lawns in Queensland and is now present in N.S.W.

species has been recorded once, from a small patch established as a garden outcast in Christchurch, New Zealand (Webb in Webb et al. 1988).

Bidens aurea (Aiton) Sherff

Arizona beggarticks

DESCRIPTION: Herb to 1 (rarely to 2.5) m high. See Strother & Weedon in Morin (2006b).

REGION OF ORIGIN: Native of southern Arizona, Mexico and Guatemala.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. The May 2004 collections are the only ones with habitat information and in this case the species was recorded from a road verge where growing with exotic species below planted Australian natives.

FIRST RECORD: Epping, *K. Aird s.n.*, 1956 (NSW).

ADDITIONAL RECORD: Castle Howard Road, Cheltenham, *P.W. Michael s.n.*, 24 Apr 1988 (NSW); Eastern side of Old Northern Rd, between Galston Rd and Mid-Dural Rd, Dural, *P.W. Michael s.n.*, 24 Apr 1988 (NSW); Castle Howard Road, Cheltenham, near footbridge over M2, *W.A. Cherry 538 & 539*, 29 May 2004 (NSW).

NOTES: Spread by seed and locally by rhizomes. The 1956 collection recorded the species as a weed '8 x 6 feet' – although it is not clear what this means. There was no information with the 1988 collections and the 2004 collections mention two patches of plants. The species has not been recorded as naturalised in other states. It has been recorded as naturalised in Portugal, Spain, France, Italy and Chile (Tutin in Tutin et al. 1976, Arroyo et al. in Mooney & Hobbs 2000).

Hieracium pilosella L.

Mouse-ear Hawkweed, Hieracium

DESCRIPTION: Herb with flowering stems to 40 cm high. See Garnock-Jones in Webb et al. (1988) and Espie (2001).

REGION OF ORIGIN: Native of Europe and Asia.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Southern Tablelands. Growing amongst snow gums and in grasslands in the Kosciuszko region.

FIRST RECORD: Namadgi National Park, Nursery Swamp, SGAP [Society for Growing Australian Plants] *s.n.*, 1992.

NOTES: Spread mainly by wind-dispersed seed and locally by stolons. There is no accurate location information with the plant collection, and the species has not been relocated in the Nursery Swamp area despite intensive searches by B.J. Lepschi, J.R. Hosking and others. This species has significantly decreased carrying capacity in large areas of the MacKenzie country on the South Island of New Zealand. *Hieracium pilosella* was found in Tasmania in January 2001 and this infestation is believed to have been eradicated (Rudman & Goninon 2002). In South Australia the species was growing in Mt Lofty Botanic Gardens in 1994 and was subsequently removed (Robyn Barker pers. comm. 4 Sep 2009). This species is also naturalised in the USA and Canada (Rickett 1966).

Mauranthemum paludosum (Poir.) Vogt & Oberpr.

DESCRIPTION: Herb to 30 cm high. See Strother in Morin (2006a) and Thompson (2007).

REGION OF ORIGIN: Native of northern Africa (Algeria, Libya, Morocco, Tunisia) and south western Europe (Spain).

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast and South Coast. From low woodland on a sandstone ridge for the Galston collection below.

FIRST RECORD: Nr Crosslands Rd, 6 km NW of Galston, *I. McDonald s.n.*, 13 Nov 1988 (NSW).

ADDITIONAL RECORDS: Princes Hwy N of Milton, *K. Mills s.n.*, 3 Jul 1998 (NSW).

NOTES: Spread by seed. The original collection was from a single plant growing on a roadside. It is also occurs in south-western Western Australia, South Australia and Victoria where it is often found on roadsides (Thompson 2007). This species is recorded as naturalised in California and New Zealand (Strother in Morin 2006a, Heenan et al. 2009).

Balsaminaceae

Impatiens balfourii Hook. f.

Poor Man's Orchid, Balfour's Touch-me-not.

DESCRIPTION: Herb to 1 m high. See Hooker (1903) and Spencer (2002b).

REGION OF ORIGIN: Native of Himalayan India and Pakistan.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Found in weedy dry sclerophyll forest.

FIRST RECORD: Bush remnant under powerline adjacent to 48 Belmore Road, North Katoomba, *C.H. Barker 52*, 18 Apr 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed and stems that root where in contact with the ground. Seeds of *I. balfourii* require cold stratification to break their dormancy and are capable of germinating after periods of drying (Tabak & von Wettberg 2008). This species appears to be increasing in the Dandenong Ranges, Victoria, and the Blue Mountains. It is also naturalised in the USA, France, Switzerland, Hungary and Italy (Hrusa et al. 2002, Moore in Tutin et al. 1968, Tabak & von Wettberg 2008).

Berberidaceae

Berberis aquifolium Pursh [syn. *Mahonia aquifolium* (Pursh) Nutt., *Berberis pinnata* Lag. misapplied, *Mahonia leschenaultii* (Wight. & Arn.) Takeda ex Dunn misapplied]

Oregon Grape

DESCRIPTION: Clonal shrub to 1.2 (rarely to 4.5) m high. See Whittemore in Morin (1997).

REGION OF ORIGIN: Native from British Columbia to northern California in North America.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands, Southern Tablelands and South Western Slopes. Mostly grows near existing plantings.

FIRST RECORD: Lankeys Creek (north of Jingellic), *E.J. McBarron 1103*, 6 Oct 1947 (NSW).

ADDITIONAL RECORDS: Mt Wilson, *E.J. Constable s.n.*, 30 Nov 1948 (NSW); 'Royalla', Robertson, *P.G. Kodela s.n.*, 13 Aug 1987 (NSW); Stromlo Forest, near Scrivener Dam, *I.R. Telford 10841*, 28 Nov 1989 (CBG, NSW); Black Mountain, lower NE slope near Botanic Gardens boundary, *I.R. Telford 10974*, 31 Oct 1990 (AD, CBG, NSW); Near reservoir, c. 700 m ESE of Cotter Dam Wall, Cotter Reserve, *B.J. Lepschi 916*, 3 Jan 1993 (AD, CANB, NSW); Near confluence of Cotter & Paddys Rivers, c. 12 km ESE of summit of Mt Coree, *B.J.*

Lepschi 3896, 14 Oct 1998 (CANB, NSW); Cooma area, *A. Grimm s.n.*, Nov 1998 (NSW); c. 200 m S of western side of Tyrolean Village and 1 km NE of Jindabyne, *J. Miles s.n.*, 24 Jul 2003 (NSW); Mount Ainslie Nature Reserve, 30 m north west of old landfill site, north of Tyson Street, Ainslie, Canberra, *C.H. Barker 75*, 17 Oct 2004 (CANB, MEL, NE, NSW); Mount Ainslie Nature Reserve, 30 m north west of old landfill site, north of Tyson Street, Ainslie, Canberra, *C.H. Barker 76*, 17 Jan 2005 (CANB, MEL, NE, NSW); Near visitor centre for Yarrongabilly Caves, Kosciusko National Park, *J.R. Hosking 2665, B. Verbeek & A.M. Beer*, 7 Dec 2005 (CANB, MEL, NE, NSW).

NOTES: Spread by bird-dispersed seed, and locally by rhizomes and rooting of layered stems. In Harden (1990) *Mahonia leschenaultii* was listed as naturalised in gullies in the Blue Mountains. Specimens under this name at CANB were sent to Alan Whittemore (NA), a recognised specialist in *Berberis* and he considered them to be *B. aquifolium* along with Australian specimens identified as this species at a later date. The *McBarron* specimen above indicated that the plant occurred in natural vegetation on a roadside. Other specimens listed the species from rainforest, a Nature Reserve near landfill, pasture and disturbed eucalypt forest and woodland. Plants are grown as ornamentals and have occasionally naturalised in the Southern Tablelands and South Western Slopes of N.S.W., and in Victoria and South Australia. *Berberis aquifolium* is invasive in central Europe and naturalised in New Zealand and outside its native range in North America (Auge & Brandl 1997, Sykes in Webb et al. 1988, Whittemore in Morin 1997).

Bignoniaceae

Podranea ricasoliana (Tanfani) Sprague

Pink Trumpet Vine

DESCRIPTION: Woody climber. See Liogier (1995) and Spencer (2002b).

REGION OF ORIGIN: Native of the eastern Cape Province and Kwazulu-Natal, South Africa.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Species recorded in the collection area were a mixture of native and exotic species.

FIRST RECORD: Mill Road, Kurrajong, dumping area off turning circle near entrance to Merroo Christian Centre driveway, *C.H. Barker 73*, 8 Dec 2004 (CANB, MEL, NE, NSW).

NOTES: Possibly only spreading vegetatively, at Kurrajong, to date. Similar to *Pandorea* spp. in appearance and habit. This genus was once part of *Pandorea* and *Podranea* is an anagram of *Pandorea* (Spencer 2002b). The species is widely planted as an ornamental. In the collection area it was growing in two patches each 15 m x 15 m and to 5 m up supporting vegetation. This species has also been recorded as naturalised in the Mt Glorious region of south eastern Queensland with the earliest collection made on 31 December 2000 (*S.P. Phillips 612, 897, 1134*). *Podranea ricasoliana* is also naturalised in Florida, Puerto Rico and New Zealand (Wunderlin & Hansen 1996+, Liogier 1995, Sykes in Webb et al. 1988).

Caprifoliaceae

Symphoricarpos albus (L.) Blake var. *laevigatus* (Fernald) S.F. Blake [syn. *Symphoricarpos rivularis* Suksd.]

Snowberry Bush

DESCRIPTION: Shrub to 3 m high. See Correa (1999) and Spencer (2002b) for the species (variety not listed) and Jones (1940) for a description without illustration.

REGION OF ORIGIN: Native from south eastern Alaska to California.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Southern Tablelands. Only known from *Eucalyptus* woodland near Yarrangobilly Caves.

FIRST RECORD: Near visitor centre for Yarrangobilly Caves, Kosciusko National Park, *J.R. Hosking 2664, B. Verbeek & A.M. Beer*, 7 Dec 2005 (CANB, MEL, NE, NSW).

NOTES: Spread by seed and suckering. Forms dense thickets. This species has also been recorded as spreading vegetatively in a garden, and persisting in an abandoned garden, in Tasmania (Matthew Baker pers. comm. 3 Sep 2009) and as a garden escape in Adelaide in 2005 (Robyn Barker pers. comm. 4 Sep 2009). *Symphoricarpos albus* is also naturalised in New Zealand, Britain, Argentina and in eastern North America (Sykes in Webb et al. 1988, Stace 1997, Correa 1999, Jones 1940).

Convolvulaceae

Convolvulus farinosus L.

Wild Bindweed

DESCRIPTION: Prostrate or climbing herb. See Meeuse & Welman (2000) and Bromilow (1995).

REGION OF ORIGIN: Native of Africa (Eritrea and Ethiopia to South Africa), Madagascar and Mascarene Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Naturalised in disturbed urban bushland.

FIRST RECORD: Maandowie Creek area, between fire trail and creekline, below Azalea Place, Loftus, *G. Broadhead s.n.*, Feb 2003 (NSW).

ADDITIONAL RECORDS: End of Azalea Place, Maandowie Bushland Reserve, Loftus, *G. & L. Broadhead s.n.*, 7 Mar 2003 (BM, NSW); Loftus, causeway 1–3 m from Maandowie Creek, Maandowie Bushland Reserve, *L. Broadhead s.n.*, 18 Dec 2006 (BRI, NSW).

NOTES: Spreads by seed. Notes supplied with the original collection indicate that there were hundreds of plants in the area and that plants could also be found outside the Reserve. *Convolvulus farinosus* is also naturalised in Portugal (Stace in Tutin et al. 1972). This species is occasionally weedy in its native range and is considered difficult to control in cultivated lands, gardens and waste places in South Africa (Meeuse & Welman 2000, Bromilow 1995).

Crassulaceae

Crassula ericoides subsp. *ericoides* Haw.

DESCRIPTION: Perennial succulent shrub to 30 cm high. See Toelken et al. in Walsh & Entwisle (1996) and van Jaarsveld in Eggli (2003).

REGION OF ORIGIN: Native of coastal areas in South Africa.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. The species is recorded as being from *Eucalytus* spp. woodland.

FIRST RECORD: 10 m from front of 80 Talbot Road, Hazelbrook, *G. Yeo s.n.*, before Mar 1998 (NSW).

NOTES: Spread by seed. Notes with the specimen mention that there were about a dozen plants in the collection area. This species is also naturalised near Anakie in Victoria (Toelken et al. in Walsh & Entwisle 1996) and was found in a single clonal patch in a roadside cutting in South Australia (Robyn Barker pers. comm. 4 Sep 2009).

Fabaceae (Faboideae)

Crotalaria retusa L.
Wedge-leaved Rattlepod

DESCRIPTION: Shrub 1.5 (rarely to 4) m high. See Dunlop et al. (1995).

REGION OF ORIGIN: Native of tropical and subtropical Africa and Asia as well as northern Australia.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast where the species was recorded from the margin between swampy pastureland and a mixture of native and exotic trees.

FIRST RECORD: Tuckean Island road, W of Wardell, *A.R. Bean 17568*, 2 Apr 2001 (BRI, NSW).

NOTES: Spread by seed. The species was listed as rare at the collection site. Plants are showy and likely to be planted for ornamental purposes. It is a weed of grain sorghum crops in the Northern Territory (Everist 1981). Plants also cause Kimberley Horse Disease, a disease initially causing weight loss and then lethargy and death of horses (Everist 1981). Seeds are toxic to fowls and pigs (Everist 1981). The problem with horses grazing plants has been overcome by fencing off river frontages where large amounts of *C. retusa* grow (Everist 1981). For more information on problems caused by *C. retusa* see Everist (1981). *Crotalaria retusa* is also naturalised on Pacific Islands, in mainland USA, Caribbean Islands and South America (Windler & Skinner in Wagner et al. 1999, Smith 1985, Fosberg et al. 1979, McMullen 1999, Isely 1998, Liogier 1988, Neill et al. in Jørgensen & León-Yánez 1999, Zarucchi in Brako & Zarucchi 1993).

Indigofera spicata Forssk.
Creeping Indigo

DESCRIPTION: Prostrate herb. See Du Puy et al. (1993) and Wilson & Rowe (2008).

REGION OF ORIGIN: Native from Ethiopia and the Central African Republic to South Africa, and to Yemen, Madagascar and Mauritius.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. No habitat information available.

FIRST RECORD: Pacific Highway road reserve, Mid Sapphire Beach, *A. Benwell s.n.*, Feb 2005 (NSW).

NOTES: Spread by movement of seed. This species is common in lawns and gardens in south eastern Queensland. Wilson & Rowe (2008) suggest that some of the plants found in Australia may be descended from plants grown in field trials as a potential fodder species. Plants are also naturalised in the Northern Territory (Wilson & Rowe 2008). There is some debate as to its toxicity as there has been confusion regarding the identification of plants that are toxic (Hutton & Guerassimoff 1966, Du Puy et al. 1993, Wilson & Rowe 2008). *Indigofera spicata* is also naturalised in Japan and on Pacific Islands (Ohashi in Iwatsuki et al. 2001, Fosberg et al. 1979, Geesink et al. in Wagner et al. 1999).

Spartium junceum L.
Spanish Broom

DESCRIPTION: Shrub to 3 m high. See Weber in Jessop & Toelken (1986) and Spencer (2002a).

REGION OF ORIGIN: Native of northern Africa (Morocco to Tunisia), Asia (Turkey to Azerbaijan, Georgia and Israel) and southern Europe.

NEW SOUTH WALES DISTRIBUTION / HABITATS: South Coast, North Western Slopes. Known as a weed in a garden and growing on a steep weed-infested river bank below gardens at Inverell.

FIRST RECORD: Candelo township, *A. Smith s.n.*, 13 Dec 2002 (NSW).

ADDITIONAL RECORD: South-east facing bank of Macintyre River, Inverell, *J.R. Hosking 2525, C.D. McLeod, L.R. Tanner & B.R. McGufficke*, 11 Nov 2004 (CANB, MEL, NSW, NE).

NOTES: Spreads by seed that is explosively released from pods. More than 100 plants were recorded growing in a garden at Candelo and over 100 plants of all ages on the riverbank at Inverell. According to G. Carr (pers. comm. Nov 2004) this species is also naturalised at Braidwood. There was a specimen collected from Braidwood in January 1930 by W.B. Henville but there is no indication of whether the specimen (now missing) was naturalised or cultivated. Like many legumes *S. junceum* is hard-seeded and seeds may germinate over a number of years (Nilsen in Bossard et al. 2000). In Australia and overseas *S. junceum* is grown as an ornamental. *Spartium junceum* is also naturalised in Victoria, Tasmania and South Australia (Carr et al. 1992, Rozefelds et al. 1999, Weber in Jessop & Toelken 1986) and overseas in New Zealand, Hawaii, mainland USA, Ecuador, Peru, Chile, South Africa and outside its native range in Europe (Webb in Webb et al. 1988, Geesink et al. in Wagner et al. 1999, Nilsen in Bossard et al. 2000, Neill et al. in Jørgensen & León-Yánez 1999, Zarucchi in Brako & Zarucchi 1993, Arroyo et al. in Mooney & Hobbs 2000, Henderson 2001, Heywood in Tutin et al. 1968).

Stylosanthes guianensis (Aubl.) Sw.
Stylo

DESCRIPTION: Annual herb to 1.5 m high. See 't Mannetje (1977) and Hacker (1990).

REGION OF ORIGIN: Native of tropical America, from southern Mexico to north eastern Argentina and Paraguay.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast, North Western Slopes. Recorded from a roadside and in pasture. In two of the locations it was recorded as growing on sandy soil, the other collection did not give soil type.

FIRST RECORD: 50 km north of Grafton on Casino road, *B. Clarke s.n.*, 4 Feb 2002 (NSW).

ADDITIONAL RECORDS: N of Brunswick Heads, *A. Benwell s.n.*, Jul 2004 (NSW); 'Pine View', 341 Yallaroi Road, Coolatai, *S. Hunt s.n.*, 30 Mar 2010 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. Introduced as a pasture species in northern Australia and now widely naturalised. This Stylo is tolerant of drought and infertile soils low in phosphorus (Hacker 1990). The collection from the Coolatai area is from plants that were introduced to the area as a seed contaminant, or as incorrectly labelled seed, and the species is spread over a large area. Two varieties are recorded in Australia, var. *guianensis* with pods indistinctly veined and var. *intermedia* with pods prominently veined (Hacker 1990). The Clarke collection does not have pods, while the Benwell collection is var. *guianensis* and the Hunt collection is var. *intermedia*. *Stylosanthes guianensis* is also naturalised in Nauru and New Caledonia (Fosberg et al. 1979, MacKee 1985).

Stylosanthes humilis Kunth
Townsville Stylo

DESCRIPTION: Annual herb to 0.5 m high. See Hacker (1990).

REGION OF ORIGIN: Native of subtropical and tropical America, from Arizona to central Brazil.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Recorded growing in sandy soil on a roadside.

FIRST RECORD: Sunshine Beach Boulevard, Byron Bay, *K. Moore s.n.*, 1 Apr 2002 (NSW).

NOTES: Spread by seed. Introduced as a pasture species in northern Australia and now widely naturalised. In Australia, this Stylo appears to be most useful where fertiliser is also added (Gillard & Winter in Stace & Edye 1984). *Stylosanthes humilis* is also naturalised in Christmas Island, Nauru and New Caledonia (Du Puy in George 1993, Fosberg et al. 1979, MacKee 1985).

Geraniaceae

***Pelargonium quercifolium* (L. f.) L'Hér.**
Oak-leaved Geranium

DESCRIPTION: Shrub to 1.75 m high. See van der Walt (1985) and Francis et al. in Spencer (2002b).

REGION OF ORIGIN: Native of South Africa (southern Cape Province).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Growing in sandy soil in *Angophora costata* and *Banksia* sp. woodland with *Pteridium esculentum* dominant in the understorey.

FIRST RECORD: Alongside Boulder Bay Road, edge of Tomaree National Park, Fingal Bay, *J.R. Hosking 2541 & G.C. Prichard*, 16 Nov 2004 (CANB, MEL, NSW, NE).

NOTES: Spread by seed. In this case the species may have spread as a result of dumping of garden waste from across the road. In the collection area it is uncommon with 2 clumps recorded, one 5 m x 3 m and the other 3 m x 2 m. The species is also naturalised on sandy soil in Victoria (*J.R. Hosking 1304 & G.W. Carr* (CANB, MEL, NSW) and *J.R.Hosking 1405* (CANB, MEL, NE, NSW)). *Pelargonium quercifolium* is also naturalised in the USA (McClintock in Hickman 1993).

Hydrangeaceae

***Hydrangea macrophylla* (Thunb.) Ser.**
Hydrangea

DESCRIPTION: Shrub to 2 m high. See Spencer (2002a).

REGION OF ORIGIN: Native of Asia (Bhutan, China, India, Japan, Myanmar and Vietnam)

NEW SOUTH WALES DISTRIBUTION / HABITATS: Northern Tablelands, Central Tablelands. Collected from the edge of cool temperate rainforest alongside a road near Werrikimbe National Park and a riparian area where growing with native and naturalised species in the Blue Mountains.

FIRST RECORD: Roadside of Cockerawombeeba Rd, between Beech Plateau and Brushy Mt adjacent to Werrikimbe National Park. *S.P. Phillips 281*, 12 Sep 1999 (BRI, MEL, NSW).

ADDITIONAL RECORDS: Adjacent to plunge pool at base of Leura Falls (not Bridal Veil Falls), *C.H. Barker 44 & D. Cameron*, 17 Mar 2004 (CANB, MEL, NE, NSW); Bushmans Range, 150 m E of junction Coramba-Dorrigo and Bushmans Range Rds, *J.J. Bruhl 2128, I.R. Telford, M.J. Waterway & M.L. Lechowicz*, 23 Mar 2004 (NE, NSW).

NOTES: Plants appear to spread via rooting of layering stems and from garden waste dumped in wet areas. This species is unlikely to be much of a problem as the species has been in cultivation for years and has not caused significant problems. There are many cultivars of

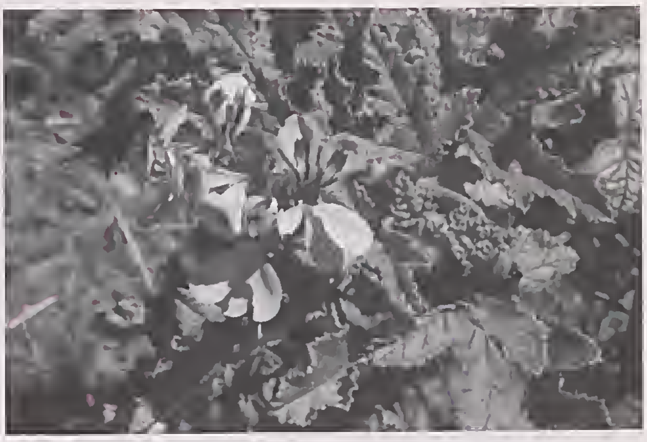

Fig. 7. *Pelargonium quercifolium* has oak-like leaves and has naturalised on sandy soils near the coast.

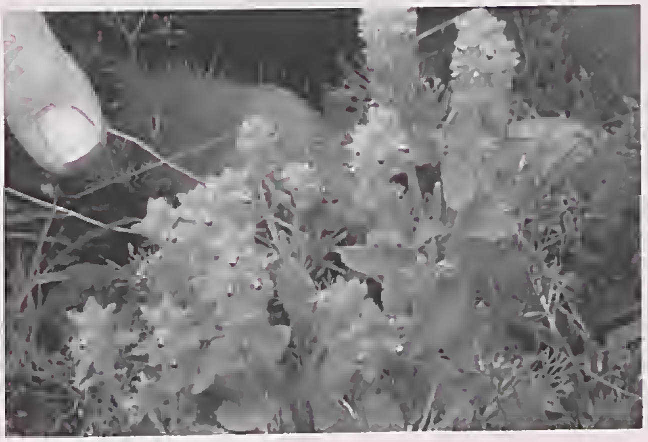

Fig. 8. *Sideritis lanata* is a weed that has been known to occur in the Inverell area for many years, but has only recently been indentified.

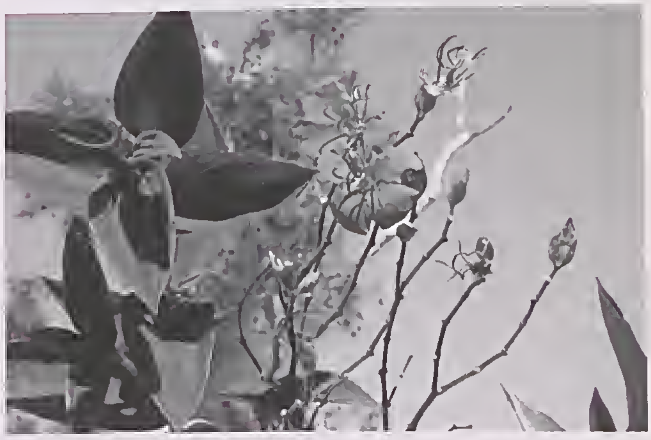

Fig. 9. *Tibouchina urvilleana* naturalises in swampy sandy areas in N.S.W.

Hydrangea (Spencer 2002a). Notes with the first record state that the species occurred in several patches, each about 2 m x 2 m, with the comment that there are no houses in the vicinity. At the Leura Falls collection location above there was only a single shrub 1.9 m high and 1.5 m wide. This shrub appears to be a cultivar in the Lacecaps group (Spencer 2002a). Notes with the Bushmans Range collection list one plant and one 2 m x 7 m clump in the area. Plants here appear to be a cultivar of the Mopheads group. In the Dandenong Ranges, Victoria, there is a watercourse that runs from closed forest to the edge of previous pasture land that has many clumps of *H. macrophylla* in both habitats (*J.R. Hosking 2425* and *J.R. Hosking 3177*). The species is also possibly naturalised in Tasmania (Matthew Baker pers. comm. 3 Sep 2009). *Hydrangea macrophylla* is naturalised in New Zealand, particularly in wetter areas (Given & Webb in Webb et al. 1988, Heenan et al. 2009) and in Peru (Liesner in Brako & Zarucchi 1993).

Hypericaceae

Hypericum calycinum L.
Aaron's Beard, Rose-of-Sharon

DESCRIPTION: Creeping rhizomatous evergreen shrub to 40 cm high. See Walsh in Walsh & Entwisle (1996).

REGION OF ORIGIN: Native of northern Turkey and south eastern Bulgaria.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. The species was recorded as growing in an area dominated by non-native species.

FIRST RECORD: Road reserve at end of Armstrong Road above Jamison Creek, Wentworth Falls, *C.H. Barker 33*, 13 Jan 2004 (BM, CANB, MEL, NE, NSW).

NOTES: Spreads locally by rhizomes. This species is also naturalised in South Australia, Victoria and Tasmania (Barker et al. 2005, Walsh in Walsh & Entwisle 1996) as well as New Zealand and the USA (Sykes in Webb et al. 1988, Hrusa et al. 2002).

Juglandaceae

Juglans ailantifolia Carrière
Japanese Walnut

DESCRIPTION: Tree to 20 (rarely to 30) m high. See Krüssmann (1986), Ohwi (1965) and Sykes in Webb et al. (1988).

REGION OF ORIGIN: Native of Japan and Russia (Sakhalin).

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Growing in weedy roadside vegetation and in neighbouring pasture.

FIRST RECORD: Alongside Mt Irvine Road, Mt Irvine, *J.R. Hosking 2450 & C.H. Barker*, 9 Feb 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed. In the collection area there were >50 trunks over 12 m x 5 m. A previous list of naturalised plants growing in the Mt Tomah area recorded the species under the name *Juglans sieboldiana* Maxim. (Ingram 1987). There is a Mt Tomah specimen (*A.M. Craig s.n.*) from cultivated plants, collected on 22 Oct 1960, at NSW. Another NSW specimen (*R. Howard-Smith s.n.*) from Mt Irvine, collected from a cultivated tree, notes that the tree was believed to have been planted in about 1910 and that 'Nuts are very prolific and germinate readily, seedlings grow rapidly with little variation in rate, used with success for grafting stock'. This species is not known to have naturalised in other Australian states. It is naturalised in New Zealand and the USA (Sykes in Webb et al. 1988, USDA, NRCS 1995+).

Lamiaceae

Sideritis lanata L.
Hairy Ironwort

DESCRIPTION: Herb to 35 cm high. See Huber-Morath in Davis (1982).

REGION OF ORIGIN: Native of Greece, Bulgaria, Yugoslavia, Turkey and east Aegean Islands.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Western Slopes. Found on roadsides and in cultivation.

FIRST RECORD: Inverell, *J. Weatherby s.n.*, 21 Oct 1969 (NSW).

ADDITIONAL RECORDS: 30 km NE of Inverell, *C. McLeod s.n.*, 28 Sep 2004 (NSW); 'Inverness', Swan Vale, Inverell Shire, *J.R. Hosking 2523, C.D. McLeod, L.R. Tanner & B.R. McGufficke*, 11 Nov 2004 (AD, BRI, BRIT, CANB, K, MEL, NSW, NE).

NOTES: Plants seed prolifically. Plants appear to have been moved with cultivation so it is not certain whether there is movement as stem or root sections or if seed movement is involved. The infested area was being grazed but this species appears to have been avoided by stock. *Sideritis lanata* is known from three properties in the Inverell district; the maximum distance between infestations being 16.5 km. In total the infestations, although consisting of many thousands of plants, only cover a few hectares. Attempts at chemical control in recent times have proved to be only partly successful. In its native range it is found in cultivated fields, waste places, *Pinus* wood, *Quercus* scrub and limestone rocks (Huber-Morath in Davis 1982). The species is listed as naturalised in Texas (Correll & Johnston 1970).

Lentibulariaceae

Utricularia sandersonii Oliver

DESCRIPTION: Herb to 7 cm high. See Conn et al. (2004).

REGION OF ORIGIN: Native of South Africa (Kwazulu-Natal).

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Only known from the splash zone of a waterfall where growing with *Zoopsis setulosa* and *Riccardia crassa*.

FIRST RECORD: Blue Mountains City Council Reserve, S of Blackheath, *A.T. Fairley s.n.*, Nov 2001 (NSW).

NOTES: Spread by fragmentation and stolon extension. Only one population of several thousand plants is known from an area of 0.3 m x 0.2 m (Conn et al. 2004). This species is widely cultivated by carnivorous plant growers (Conn et al. 2004). This species is also starting to naturalise in New Zealand (Heenan et al. 2004). For more information on this species and the possibility of the species being native see Conn et al. (2004).

Melastomataceae

Melastoma malabathricum L.
Banks Melastoma

DESCRIPTION: Shrub or small tree to 5 m high. See Holm et al. (1997) and Meyer (2001) for a broad concept of *M. malabathricum* or Whiffin in George (1990) for a narrower concept of *M. malabathricum*.

REGION OF ORIGIN: Native of western Indian Ocean islands across southern Asia to Micronesia, Malesia and Polynesia (if a broad concept of the species is adopted – it is unclear where a less broadly defined species would occur).

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Recorded growing on sand in native bush with privet and lantana.

FIRST RECORD: Warraroon Res(erve), Lane Cove, *Van Klaphake 155*. 1 May 1987.

NOTES: Spread by seed. Meyer (2001) sunk the Australian native *Melastoma* species *Melastoma affine* D.Don and *Melastoma denticulatum* Labill. into a broadly circumscribed *M. malabathricum.* This has not been accepted in Australia where the only native species is considered to be *M. affine* (Whiffin in George 1990, APC 2005+). The species naturalised in the Lane Cove area of Sydney has a longer calyx than the taxa considered native to Australia, and the Sydney region is outside the native range of *Melastoma* in Australia. Notes associated with the specimen are 'Occasional weed in a number of bushland reserves in Lane Cove area.' The species is considered to be a weed of pastures and crops in much of its native range (Holm et al. 1997).

Tibouchina urvilleana **(DC.) Cogn.**

Glorybush

DESCRIPTION: Shrub to 2.2 m high. See Almeda in Wagner et al. (1999) and Spencer (2002a).

REGION OF ORIGIN: Native of southern Brazil.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast, North Coast. Recorded from a weedy gully at Lugarno, swampy areas near Nelson Bay and an old *Eucalyptus pilularis* plantation with a rainforest understory in Nightcap National Park.

FIRST RECORD: Evatt Park, Lugarno, Sydney, *M.J. Mulvaney s.n.*, 23 May 1987 (CANB).

ADDITIONAL RECORDS: Behind Fairlands Road, Tanilba Bay, *J.R. Hosking 2534 & G.C. Prichard*, 15 Nov 2004 (CANB, MEL, NE, NSW); Junction of Minyon Drive and Peates Mountain Road, Nightcap National Park, *P.H. Weston 3141 & R.M. Kooyman*, 8 Mar 2008 (NSW).

NOTES: Spread by seed. The Lugarno collection was from a single plant with the comment that there may have once been more plants as the area had been weeded by bush regenerators. Notes with the Tanilba Bay collection indicate that it was locally common (about 25 plants >1 m high and 100s of smaller plants) shrub to 2.2 m high at Tanilba Bay and that it was also naturalised in Mamba Wetlands, alongside Port Stephens Drive, Salamander Bay (where there were about 15 plants >1 m high and many more smaller plants). The Nightcap National Park collection lists the species as being common and with numerous seedlings beneath. *Tibouchina urvilleana* is also naturalised in Queensland (Bean in Bostock & Holland 2007) with the first specimen of a naturalised plant collected in 1970 (*Swarbrick 5689* - BRI). It is also naturalised in New Zealand and Hawaii (Sykes in Webb et al. 1988, Almeda in Wagner et al. 1999).

Moraceae

Ficus carica **L.**

Common Fig

DESCRIPTION: Tree to 10 m high. See Spencer (1997), Wunderlin in Morin (1997), Randall in Bossard et al. (2000) and Wu et al. in Wu & Raven (2003).

REGION OF ORIGIN: Native of southern Europe (southern France to Greece), Mediterranean Islands, Asia (Turkey to Sinai, Azerbaijan and northern Pakistan), northern Africa (Morocco to Tunisia), although the exact native range is now obscure.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast, Western Slopes. Scattered trees known mostly from alongside watercourses on the Western Slopes.

FIRST RECORD: Oxley Park, Tamworth, *J.R. Hosking 896*, 9 Dec 1993 (CBG, MEL, NE, NSW).

ADDITIONAL RECORDS: c. 4.5 km from Cowra towards Boorowa, near Morongla Creek crossing, *D.L. Jones 17873 & K.J. FitzGerald*, 21 Mar 2001 (CANB); 1.5 km N of Wee Jasper on road to Carey's Caves Reserve, *B.J. Lepschi 4641 & A.J. Whalen*, 14 Nov 2001 (CANB, MEL, NSW); Hungerford Creek Valley, north of Glen Gallic Fire Trail (Wollemi National Park), south south east of village of Baerami, *C.H. Barker 69*, 15 Oct 2004 (CANB, MEL, NE, NSW).

NOTES: Spread by seed, locally by root suckers and vegetatively via limbs that break off and take root. The Hosking 896 and Lepschi 4641 & Whalen collections were from single fruiting trees while the Barker 69 specimen was from a group of four trees, two of which were fruiting, and Jones 17873 & Fitzgerald was from a group of three adventive plants. The authors have often encountered single plants alongside watercourses. Possibly 'fruit' are discarded by humans or are eaten by animals and birds alongside watercourses and plants arise from discarded 'fruit' or animal dispersed seed. *Ficus carica* is listed as naturalised in South Australia and Western Australia (Jessop in Jessop & Toelken 1986, Hussey et al. 2007) and doubtfully naturalised in Queensland and Victoria (Jessup in Bostock & Holland 2007, Walsh & Stajsic 2007). The species is widely naturalised around the world (Tutin in Tutin et al. 1993, Webb in Webb et al. 1988, Randall in Bossard et al. 2000, Tassin et al. 2006, Berg in Jørgensen and León-Yánez 1999). It is considered to be a weed in California where it may invade and dominate riparian forests, streamside habitats, levees and canal banks (Randall in Bossard et al. 2000).

Myrtaceae

Corymbia citriodora **(Hook.) K.D. Hill & L.A.S. Johnson**

[syn. *Eucalyptus citriodora* Hook.]

Lemon-scented Gum

DESCRIPTION: Tree to 40 (occasionally to 50) m high. See Chippendale in George (1988).

REGION OF ORIGIN: Native of Queensland.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. One of the C. Burgess collections from Beecroft lists the species as forming a naturalised community in *Eucalyptus pilularis* forest. At North Richmond plants are growing in an ironbark woodland cleared for grazing. Here cattle damage young *C. citriodora* but not enough to prevent growth.

FIRST RECORD: Beecroft, *C. Burgess s.n.*, 15 Mar 1963 (CANB).

ADDITIONAL RECORDS: Pennant Hills, *C. Burgess s.n.*, 15 Mar 1963 (CANB); Beecroft, *C. Burgess s.n.*, 9 May 1963 (CANB); Near Saint John of God Hospital, south of Grose Vale Road, North Richmond, *C.H. Barker 74*, 10 Dec 2004.

NOTES: Spread by seed. Collections by C. Burgess list the species as a 'naturalised community' at Beecroft in Mar 1963 and as a 'garden escape' at Pennant Hills in Mar 1963. Notes with the other C. Burgess collections list the species as forming naturalised communities. At North Richmond around 10 pole-like trees at heights around 13–15 m and around 80 saplings 1–10 m high were recorded growing around an 18 m high parent tree. *Corymbia citriodora* is also known to be naturalising at Scheyville National Park, the Australian Defence Industries (ADI) site Saint Marys (P. Mohbs pers. comm. 2004), Yarramundi and Greystanes. This species is also naturalised in Victoria and Western Australia (Walsh & Stajsic 2007, Keighery pers. comm.)

and questionably naturalised in South Australia (Robyn Barker pers. comm. 7 Sep 2009). Overseas *C. citriodora* is naturalised in California, Hawaii and Wake Island (McClintock in Hickman 1993, Wagner et al. 1999, Fosberg et al. 1979).

Eugenia uniflora L.
Brazilian Cherry

DESCRIPTION: Small tree or shrub to 3 (rarely to 8) m high. See Henderson (2001).

REGION OF ORIGIN: Native of northern Argentina, Bolivia, Brazil, Paraguay and Uruguay

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Collected from subtropical rainforest regrowth (50 years) according to label information.

FIRST RECORD: Bilambil Heights, 4 km SW of Tweed Heads, *C. Roberts s.n.*, 8 Mar 2000 (CANB, NSW).

NOTES: Spread by animal-dispersed seed. This species is widely cultivated for its edible fruit, as an ornamental and for hedging. It is now naturalised in coastal areas of Queensland (Bean et al. in Bostock & Holland 2007) and in many tropical and sub-tropical countries around the world (Fosberg et al. 1979, Henderson 2001, Wagner et al. 1999).

Syzygium paniculatum Gaertn.
Brush Cherry

DESCRIPTION: Shrub or small tree to 14 m high. See Wilson in Harden (2002) and Spencer (2002a).

REGION OF ORIGIN: Native of coastal New South Wales.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Western Slopes. Volunteering in a garden in an area regularly watered.

FIRST RECORD: 46 Dibar Drive, Tamworth, *J. Kneipp s.n.*, 30 Nov 2004 (NSW).

ADDITIONAL RECORDS: Possibly Ourimbah Creek Road, c. 10 km west of Pacific Highway, *H. Bryant 317 & H. Fallding*, 5 Apr 1979.

NOTES: Spread by seed. The species is widely cultivated and likely to naturalise in wet areas. It is listed as endangered under the *NSW Threatened Species Conservation Act 1995*. Only a single volunteer plant is known from the Tamworth area and this was in an artificially wet area. Notes with the Ourimbah Creek Road specimen list the species as occurring on recent alluvium and is likely to be native. *Syzgium paniculatum* may spread in moist areas of bushland reserves in Sydney, where it is apparently not native, but originates from cultivated street and garden plants.

Papaveraceae

Romneya coulteri Harv.
Matilija Poppy, California Tree Poppy

DESCRIPTION: Perennial herb to 2 m high. See Clark in Morin (1997) and Spencer (1997).

REGION OF ORIGIN: Native of south western California.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Southern Tablelands. Collected from a roadside at Yarralumla. The species also grows in a rail reserve in Hume Shire.

FIRST RECORD: In front of the Commonwealth Club, Canberra [Forster Crescent, Yarralumla], *N. Burbidge s.n.*, 2 Dec 1965 (CANB, NSW).

NOTES: Spread by seed. The collection from in front of the Commonwealth Club has been treated as wild as it appears to match the species information in Burbidge and Gray (1979) where the species is noted as 'a garden escape persistent in the Forrest-Yarralumla-lakeside area'. The species was also found in Hume Shire in late 2005 and identified from digital images but a specimen does not appear to have been sent to NSW.

Romneya trichocalyx Eastw.
Hairy Matilija Poppy

DESCRIPTION: Perennial herb to 2 m high. See Clark in Morin (1997) and Spencer (1997).

REGION OF ORIGIN: Native of south western California and northern Baja Norte.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Southern Tablelands, South Western Slopes. *Mowle 181* from central Canberra is recorded as 'growing by roadside on slope with grasses and weeds'. *Milvain s.n.* is also recorded from a roadside, but associated vegetation was not listed.

FIRST RECORD: National Circuit, Capital Hill area, *K. Mowle 181*, 7 Dec 1964 (CANB).

ADDITIONAL RECORD: S of Yerong Creek, *H. Milvain s.n.*, 12 Dec 1991 (NSW).

NOTES: Spread by seed. No information on abundance is recorded for *Mowle 181*, and this taxon (and the related *R. coulteri*) have not persisted in the ACT. Collector's notes for *Milvain s.n.* indicate that plants covered 100 square metres. The species is closely related and sometimes merged with *Romneya coulteri* Harvey. *Romneya trichocalyx* is also naturalised in Western Australia (FloraBase 1998+).

Primulaceae

Primula malacoides Franch.
Fairy Primrose

DESCRIPTION: Herb to over 30 cm high. See Richards (1993) and Spencer (1997).

REGION OF ORIGIN: Native of China (western Guangxi, Guizhou, Yunnan) and north eastern Myanmar.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Recorded from creeklines.

FIRST RECORD: Near M2 crossing of Darling Mills Creek, on tributary running from Cook Street, Baulkam Hills, *W.A. Cherry 545*, 28 Aug 2004 (NSW).

NOTES: Spread by seed. The species is recorded as occasional in the collection area and also along Darling Mills Creek. *Primula malacoides* also occurs in Hunts Creek to the south east of the collection area (W Cherry pers. comm. 9 Apr 2010). This species has not previously been recorded as naturalised in Australia. *Primula malacoides* is also naturalised in New Zealand (Webb et al. 1995).

Proteaceae

Hakea laurina R.Br.
Pincushion Hakea

DESCRIPTION: Shrub or small tree to 6 m high. See Barker et al. in Wilson (1999) and Spencer (2002a).

REGION OF ORIGIN: Native of south western Western Australia.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Northern Tablelands. South Western Slopes. Recorded from dry sclerophyll forest growing on light sandy soil at Howes valley and from metasediments in a woodland at South Wagga Wagga.

FIRST RECORD: 14 miles south of Howes valley, *E. Bird s.n.*, May 1969 (Tamworth Agricultural Research Institute herbarium).

ADDITIONAL RECORD: Willans Hill Reserve, South Wagga Wagga, c. 400 m S of intersection of Lord Baden Powell Drive and Captain Cook Drive; within 5 m of Captain Cook Drive, *A. Mnyt 4*, 23 Sep 2005 (CANB, NSW).

NOTES: Spread by seed. The specimen from Howes valley notes that the species is possibly a recent garden escape. The collection from South Wagga Wagga is recorded as being 'Part of a concentrated population of c. 20 plants covering an area 20 m x 20 m. All plants < 2 m high and appearing even aged. No fruits apparent on any plants; flowering just starting. Population is not planted, but may have originated from planted stock.' Naturalised in South Australia (Barker et al. in Wilson 1999) and outside its native range in Western Australia, as well as doubtfully naturalised in Victoria (Walsh & Stajsic 2007). A few plants have been recorded outside cultivation in Tasmania (Matthew Baker pers. comm. 11 Sep 2009).

Ranunculaceae

Anemone hupehensis Lemoine var. *japonica* (Thunb.) Bowles & Stearn

Japanese Windflower

DESCRIPTION: Herb to 1 m high. See Kadota in Iwatsuki et al. (2006) and Duncan in Wagner et al. (1999).

REGION OF ORIGIN: Horticulture, derived from *A. hupehensis*.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Recorded from sandy loam soil in shrubby dry sclerophyll forest.

FIRST RECORD: North side of Great Western Highway, near top of Boddington Hill, Wentworth Falls, *C.H. Barker 49*, 12 Apr 2004 (CANB, MEL, NE, NSW).

NOTES: Probably spreads as a result of rhizome growth. Appears to result from dumped garden waste, spread over 4 m x 3 m at the time of collection. This species is not known to occur outside cultivation elsewhere in Australia. It is cultivated and naturalised in Japan and Hawaii (Kadota in Iwatsuki et al. 2006, Duncan in Wagner et al. 1999).

Rosaceae (spiraeoideae)

Rhaphiolepis umbellata (Thunb.) Makino

Japanese Hawthorn, Yeddo Hawthorn

DESCRIPTION: Shrub to 3 m high. See Given & Sykes in Webb et al. (1988) and Spencer (2002a).

REGION OF ORIGIN: Native of China, Taiwan, Japan and Korea (Quelpaert Island).

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast and South Coast. Growing in a shrub thicket on the north coast and in coastal woodland on sand below a cliff on the south coast.

FIRST RECORDS: Arrawarra Headland, *H.J. Wissmann*, 12 Apr 1991 (NE).

ADDITIONAL RECORDS: Harbour Beach, north of harbour, Ulladulla, *A. Pulford a*, 26 Mar 2004 (NSW); Harbour Beach, west side of beach, Ulladulla, *A. Pulford b*, 26 Mar 2004 (NSW); Narrawallee Beach near Ulladula, *T.C. Chambers s.n.*, 7 Jul 2006 (NSW, CANB).

NOTES: A species that was once common in cultivation. Probably spread by bird-dispersed seed. The species was first collected by Hans Wissmann in 1991 and the specimen label lists shrubs 3 m high in a shrub thicket on Arrawarra Headland. It was also noted by Carrick Chambers (NSW) in June 2002 and was collected by Arthur Pulford at Chamber's request. Notes with the Chamber's specimen indicate that plants are naturalised behind sand dunes. This species is not known to be naturalised elsewhere in Australia but is recorded as naturalised in New Zealand, where most naturalised plants appear to occur around previous plantings or in disturbed areas (Given & Sykes in Webb et al. 1988), and on Norfolk Island (Green in Wilson 1994).

Sorbus aucuparia L.

Rowan

DESCRIPTION: Small deciduous tree to 10 m high. See Spencer (2002a).

REGION OF ORIGIN: Native of Europe, Iceland and Asia.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Tablelands. Recorded on sandy soil in open forest.

FIRST RECORD: Alongside Bureau Park, North Katoomba, *J.R. Hosking 2435 & C.H. Barker*. 7 Feb 2004 (AD, CANB, MEL, NE, NSW).

NOTES: Mostly spread by animal-dispersed seed, mainly by birds and to a lesser extent by mammals (Pías & Guitián 2006). A single naturalised fruiting tree and a seedling were found in the collection area. At this site many of the fruit appeared to have been partly eaten by birds. *Sorbus aucuparia* is recorded as naturalised in Tasmania (Buchanan 2009) and doubtfully naturalised in Victoria and South Australia (Walsh & Stajsic 2009, eFlora SA 1999+). It is also naturalised in New Zealand and North America (Given & Sykes in Webb et al. 1988, Rosatti in Hickman 1993, USDA, NRCS 1995+).

Scrophulariaceae (Buddlejeae)

Buddleja dysophylla (Benth.) Radlk.

DESCRIPTION: Climbing shrub to 4 m high on supporting vegetation. See Stuart (2006).

REGION OF ORIGIN: Native of eastern South Africa to Tanzania and Zaire.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Recorded from bushland, and a track edge on boundary of moist forest associated with tributary of Narara Creek and cleared land.

FIRST RECORD: Oatley, *G. Chippendale s.n.*, 21 Jun 1953 (NSW).

ADDITIONAL RECORDS: Narara (north Gosford), *N. Corkish s.n.*, 4 Jul 2005 (NSW); Smalls Creek, end of Acres Rd, Kellyville, *I. Charlton s.n.*, 20 Jul 2005 (NSW).

NOTES: Spread by seed and will grow from stem fragments. Notes with the 1953 collection suggest that the species was naturalised at this time 'scrambling over many other shrubs, extending into bushland'. Notes with the Charlton collection mention that the plant is forming a thicket. This species is also naturalised in Victoria and Western Australia (Walsh & Stajsic 2007, FloraBase 1998+) and New Zealand (Sykes in Webb et al. 1988). There is also an 'Extensive infestation climbing high over native vegetation' on King Island (Matthew Baker pers. comm. 11 Sep 2009).

Solanaceae

***Brugmansia suaveolens* (Humb. & Bonpl. ex Willd.) Bercht. & J. Presl** [syn. *Datura suaveolens* Humb. & Bonpl. ex Willd.]
Angel's Trumpet

DESCRIPTION: Shrub to 3 m high. See Hunziker (2001), Schultes in Hawkes et al. (1979), Shaw in Cullen et al. (2000) and Spencer (2002b).

REGION OF ORIGIN: Native of Bolivia, Brazil and Peru.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Growing alongside streams.

FIRST RECORD: Bellinger River, near junction with Boggy Creek, *S. Jacobs 6702*, 21 Nov 1992 (NSW).

ADDITIONAL RECORD: Byrangery Creek, 4.2 km [actually 3 km based on the GPS location] NNW of Federal, *S. Kidman s.n.*, 16 Nov 2005 (CANB, NSW).

NOTES: Spreads by suckering, rooting of broken pieces and possibly by seed. The species was recorded as naturalised and common in a shady gully leading down to the Bellinger River. According to Iain Jamieson (pers. comm. 15 Feb 2006) the infestation of *Brugmansia suaveolens* near Byron Bay runs for 3–4 kilometres along Byrangery Creek and one of his staff believes it has been there for at least 20 years and has spread slowly over that period. Plants occur singly or in small groups along both sides of the creek. *Brugmansia suaveolens* is also naturalised in New Zealand, Norfolk Island, Florida and Puerto Rico (Sykes in Webb et al. 1988, Green in Wilson 1994, Wunderlin & Hansen 1996+, Liogier 1995).

***Brugmansia* x *candida* Pers.**
Angel's Trumpet

DESCRIPTION: Shrub to 5 m high. See Schultes in Hawkes et al. (1979), Shaw in Cullen et al. (2000), Roy et al. (1998) & Spencer (2002b).

REGION OF ORIGIN: Native of Ecuador and Peru.

NEW SOUTH WALES DISTRIBUTION / HABITATS: Central Coast. Recorded growing on alluvium under native trees.

FIRST RECORD: 8 km W of Wyong on Yarramalong road, near Wyong Creek, *B. Briggs 7133 & L.A.S. Johnson*, 29 Nov 1980 (NSW).

NOTES: Spread possibly as a result of dumped garden waste or rooting of broken pieces. Notes with the collection indicate that occasional plants were present along the roadside and were growing to 1.5 m high. *Brugmansia* x *candida* has naturalised in New Zealand, Hawaii and the Galapogos Islands (Sykes in Webb et al. 1988, Roy et al. 1998, Symon in Wagner et al. 1999, Tye in Groves et al. 2001)

Tetrachondraceae

***Polypremum procumbens* L.**
Juniper Leaf, Rustweed

DESCRIPTION: Perennial procumbent or ascending forb. See Liogier (1995), Diggs et al. (1999) and Norman (2000).

REGION OF ORIGIN: Native of North and South America, from north eastern and north central USA to Paraguay.

NEW SOUTH WALES DISTRIBUTION / HABITATS: North Coast. Collected from open wet area adjacent to *Melaleuca quinquinervia* forest.

FIRST RECORD: Coolangatta Airport, Tweed Heads West, *A.R. Bean 15228*, 28 Jun 1999 (BRI, NSW).

NOTES: Spread by seed. Also recorded from the Queensland side of the same airport (*D. Halford Q3831 & G. Leiper* – BRI, MEL, NSW). Not known to be naturalised elsewhere in Australia. The species is considered to be weedy (Correll & Johnston 1970, Liogier 1995).

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References

Anon. (2003) Hymenachne or Olive hymenachne (*Hymenachne amplexicaulis*). Weed Management Guide. Weeds of National Significance. CRC for Australian Weed Management and the Commonwealth Department of the Environment and Heritage.

APC (2005+) Australian Plant Census. http://www.anbg.gov.au/chah/apc/index.html (viewed 9 August 2010).

APNI (1993+) Australian Plant Name Index, http://www.anbg.gov.au/cgi-bin/apni (viewed 9 August 2010).

Arnold, T. H. & de Wet, B.C. (Eds) (1993) *Plants of southern Africa: names and distribution*. Memoirs of the botanical survey of South Africa No. 62. (National Botanical Institute: Pretoria).

Auge, H. & Brandl, R. (1997) Seedling recruitment in the invasive clonal shrub, *Mahonia aquifolium* Pursh (Nutt.). *Oecologia* 110: 205–211.

Barker, W.R., Barker, R.M., Jessop, J.P. & Vonow, H.P. (Eds) (2005) *Census of South Australian vascular plants*. 5th Edition. *Journal of the Adelaide Botanic Gardens Supplement 1*. (Botanic Gardens of Adelaide and State Herbarium: Adelaide).

Barrow, S.C. (1998) A monograph of *Phoenix* L. (Palmae: Coryphoideae). *Kew Bulletin* 53: 513–575.

Boorman, D. (2009). Ponded pasture grasses *Hymenachne amplexicaulis* (Rudge) Nees (Hymenachne) and *Echinochloa polystachya* (Kunth) A.S.Hitch. cv 'Amity' (Aleman grass) and the potential for spread of invasive weeds. 12th Biennial NSW Weeds Conference, 14–15 September 2009, Narrabri. (CD of proceedings available from Industry & Investment NSW, Orange).

Bossard, C.C., Randall, J.M. & Hoshovsky, M.C. (Eds) (2000) *Invasive plants of California's wildlands* (University of California Press: Berkeley and Los Angles).

Bostock, P.D. & Holland, A.E. (Eds) (2007) *Names and distribution of Queensland plants, algae and lichens* (Queensland Herbarium: Environment Protection Agency, Brisbane).

Brako, L. & Zarucchi, J.L. (1993) *Catalogue of the flowering plants and gymnosperms of Peru* (Missouri Botanic Garden: St Louis).

Bromilow, C. (1995) *Problem plants of South Africa* (Briza Publications: Arcadia, South Africa).

Buchanan, A.M. ed. (2009) *A census of the vascular plants of Tasmania & index to The Student's Flora of Tasmania* 2009 Edition (Tasmanian Herbarium: Hobart).

Burbidge, N.T. & Gray, M. (1979) *Flora of the Australian Capital Territory.* (ANU Press: Canberra).

Burns, J.H. (2004) A comparison of invasive and non-invasive dayflowers (Commelinaceae) across experimental nutrient and water gradients. *Diversity and Distributions* 10: 387–397.

Burns, J.H. & Winn, A.A. (2006) A comparison of plastic responses to competition by invasive and non-invasive congeners in Commelinaceae. *Diversity and Distributions* 12: 797–807.

Carr, G.W., Yugovic, J.V. & Robinson, K.E. (1992) *Environmental weed invasions in Victoria: conservation and management implications* (Department of Conservation and Environment and Ecological Horticulture Pty. Ltd.: Melbourne).

Conn, B.J., Brown, E.A. & Fairley, A.T. (2004) *Utricularia sandersonii* (Lentibulariaceae), a new record for Australia. *Telopea* 10: 811–814.

Correa, M.N. (1999) *Flora Patagonia.* Parte VI (Instituto Nacional de Technologia Agropecuaria: Buenos Aires).

Correll, D.S. & Johnston, M.C. (1970) *Manual of the vascular plants of Texas* (Texas Research Foundation: Renner, Texas).

Cowie, I. & Kerrigan, R. (2007) *Introduced flora of the Northern Territory* (generated March 2007) (Northern Territory Herbarium: Northern Territory Government, Natural Resources, Environment, The Arts and Sport).

Cullen, J., Alexander, J.C.M., Brickell, C.D., Edmondson, J.R., Green, P.S., Heywood, V.H., Jørgensen, P.-M., Jury, S.L., Knees, S.G., Maxwell, H.S., Miller, D.M., Robson, N.K.B., Walters, S.M. & Yeo, P.F. (2000) *The European garden flora. Dicotyledons (Part IV).* Volume VI (Cambridge University Press: Cambridge).

Cunningham, G.M., Mulham, W.E., Milthorpe, P.L. & Leigh, J.H. (1981) *Plants of western New South Wales* (NSW Government Printer: Sydney).

Curtis, W.M. & Morris, D.I. (1994) *The student's flora of Tasmania.* Volume 4B (St. David's Park Publishing: Hobart).

Davis, P.H. (Ed.) (1982) *Flora of Turkey and the East Aegean Islands.* Volume 7 (Edinburgh University Press: Edinburgh).

Diaz, R., Overholt, W.A., Cuda, J.P., Pratt, P.D. & Fox, A. (2009) Host specificity of *Ischnodemus variegatus*, an herbivore of West Indian marsh grass (*Hymenachne amplexicaulis*). *BioControl* 54: 307–321.

Diggs, G.M.Jr., Lipscomb, B.L. & O'Kennon, R.J. (1999). Shinners and Mahler's illustrated flora of north central Texas. *Sida, Botanical Miscellany* No. 16 (Botanical Research Institute of Texas and Austin College: Fort Worth, Texas).

Diggs, G.M.Jr., Lipscomb, B.L., Reed, M.D. & O'Kennon, R.J. (2006) Illustrated flora of east Texas. *Sida, Botanical Miscellany* No. 26 (Botanical Research Institute of Texas and Austin College: Fort Worth, Texas).

Dunlop, C.R., Leach, G.J. & Cowie, I.D. (1995) *Flora of the Darwin region.* Volume 2 (Conservation Commission of the Northern Territory: Palmerston, Northern Territory).

Du Puy, D.J., Labat, J.-N. & Schrire, B.D. (1993) The separation of two previously confused species in the *Indigofera spicata* complex (Leguminosae: Papilionoideae). *Kew Bulletin* 48: 727–733.

Dyer, R.A., Codd, L.E. & Rycroft, H.B. (1963) *Flora of South Africa.* Volume 26 (Government Printer: Pretoria).

eFlora SA (1999+) Electronic flora of South Australia. State Herbarium of South Australia, http://www.flora.sa.gov.au (viewed 9 August 2010).

Eggli, U. (2001) *Illustrated handbook of succulent plants: Monocotyledons* (Springer: Berlin).

Eggli, U. (2003) *Illustrated handbook of succulent plants: Crassulaceae* (Springer: Berlin).

Espie, P. (2001) *Hieracium in New Zealand: ecology and management* (AgResearch Ltd.: Mosgiel).

Everist, S.L. (1981) *Poisonous plants of Australia.* 2nd Edition (Angus and Robertson: Sydney).

Farjon, A. & Styles, B.T. (1997) *Pinus* (Pinaceae). Flora Neotropica Monograph 75 (The New York Botanical Garden: New York, USA).

Ferren, W.R.Jr., Bleck, J. & Vivrette, N. (1981) *Malephora crocea* (Aizoaceae) naturalized in California. *Madroño* 28: 80–85.

FloraBase (1998+) Florabase – The Western Australian Flora, Western Australian Herbarium, http://florabase.calm.wa.gov.au (viewed 9 August 2010).

Fosberg, F.R., Sachet, M.-H. & Oliver, R. (1979) A geographical checklist of the Micronesian Dicotyledonae. *Micronesica* 15: 41–295.

George, A.S. (Ed.) (1988) *Flora of Australia.* Volume 19, Myrtaceae – Eucalyptus, Angophora (Australian Government Publishing Service: Canberra).

George, A.S. (Ed.) (1990) *Flora of Australia.* Volume 18, Podostemaceae to Combretaceae (Australian Government Publishing Service: Canberra).

George, A.S. (Ed.) (1993) *Flora of Australia.* Volume 50, Oceanic islands 2 (Australian Publishing Service: Canberra).

Goldblatt, P. & Manning, J. (1998) *Gladiolus in southern Africa* (Fernwood Press: Vlaeberg, South Africa).

Griffin, R.M., Webster, E.P., Zhang, W. & Blouin, D.C. (2008) Biology and control of creeping rivergrass (*Echinochloa polystachya*) in rice. *Weed Technology* 22: 1–7.

Groves, R.H., Panetta, F.D. & Virtue, J.G. (Eds) (2001) *Weed risk assessment* (CSIRO Publishing: Collingwood).

Hacker, J. (1990) *A guide to herbaceous and shrub legumes of Queensland* (University of Queensland Press, St Lucia).

Haines, R.W. & Lye, K.A. (1983) *The sedges and rushes of East Africa* (East African Natural History Society: Nairobi).

Harden, G. J. (Ed.) (1990) *Flora of New South Wales.* Volume 1 (New South Wales University Press: Sydney).

Harden, G.J. (Ed.) (2002) *Flora of New South Wales.* Volume 2. Revised edition (University of New South Wales Press: Sydney).

Harden, G.J. & Murray, L.J. (Eds) (2000) *Supplement to Flora of New South Wales* Volume 1 (University of New South Wales Press: Sydney).

Hawkes, J.G.; Lester. R.N. & Skelding, A.D. (1979) *The biology and taxonomy of the Solanaceae* (Academic Press: London).

Healy, A.J. & Edgar, E. (1980) *Flora of New Zealand.* Volume 3 (Government Printer: Wellington).

Heenan, P.B., de Lange, P.J., Cameron, E.K., Ogle, C.C. & Champion, P.D. (2004) Checklist of dicotyledons, gymnosperms and pteridophytes naturalised or casual in New Zealand: additional records 2001–2003. *New Zealand Journal of Botany* 42: 797–814.

Heenan, P.B., de Lange, P.J., Glenny, D.S., Breitwieser, I., Brownsey, P.J. & Ogle, C.C. (1999) Checklist of dicotyledons, gymnosperms and pteridophytes naturalised or casual in New Zealand: additional records 1997–1998. *New Zealand Journal of Botany* 37: 629–642.

Heenan, P.B., de Lange, P.J., Rance, B.D., Sykes, W.R., Meurk, C.D. & Korver, M.A. (2009) Additional records of indigenous and naturalised plants with observations on the distribution of *Gunnera tinctoria,* on Stewart Island, New Zealand. *New Zealand Journal of Botany* 47: 1–7.

Henderson, L. (2001) *Alien weeds and invasive plants.* Plant Protection Research Institute Handbook No. 12 (Agricultural Research Council: Cape Town).

Hickman, J.C. (Ed.) (1993) *The Jepson manual: higher plants of California* (University of California Press: Berkeley and Los Angeles).

Holm, L., Doll, J., Holm, E., Pancho, J. & Herberger, J. (1997) *World weeds: natural histories and distribution* (John Wiley and Sons: New York).

Holm, L., Pancho, J.V., Herberger, J.P. & Plucknett, D.L. (1979) *A geographical atlas of world weeds* (John Wiley and Sons: Toronto).

Holmgren, P.K., Holmgren, N.H. & Barnett, L.C. (1990) *Index herbariorum Part 1: the herbaria of the world.* 8th Edition (New York Botanical Gardens: Bronx, New York).

Hooker, J.D. (1903) *Impatiens balfourii. Curtis's Botanical Magazine* 129 t. 7878.

Hooker, W.J. (1825) *Zephyranthes carinata. Curtis's Botanical Magazine* 52 t. 2594.

Hosking, J.R., Conn, B.J. & Lepschi, B.J. (2001) Detection of recent plant naturalisations in New South Wales. 11th Biennial Noxious Weeds Conference, 4–6 September 2001, Moama. pp. 136–139 (NSW Agriculture: Orange).

Hosking, J.R., Conn, B.J. & Lepschi, B.J. (2003) Plant species first recognised as naturalised for New South Wales over the period 2000–2001. *Cunninghamia* 8: 175–187.

Hosking, J.R., Conn, B.J., Lepschi, B.J. & Barker, C.H. (2007) Plant species first recognised as naturalised for New South Wales in 2002 and 2003 with additional comments on species recognised as naturalised in 2000–2001. *Cunninghamia* 10: 139–166.

Hrusa, F., Ertter, B., Sanders, A., Leppig, G. & Dean, E. (2002) Catalogue of non-native vascular plants occurring spontaneously in California beyond those addressed in *The Jepson Manual* – Part 1. *Madroño* 49: 61–98.

Hunziker, A.T. (2001) *Genera Solanacearum.* (A.R.G. Gantner Verlag K.-G.: Ruggell).

Hussey, B.M.J., Keighery, G.J., Dodd, J., Lloyd, S.G. & Cousens, R.D. (2007) *Western weeds: a guide to the weeds of Western Australia.* 2nd edition (The Plant Protection Society of Western Australia (Inc.): Perth).

Hutton, E.M. & Guerassimoff, J. (1966). Problems in breeding the legume *Indigofera spicata* for tropical pastures. *Euphytica* 15: 353–361.

Ingram, C.K. (1987) Checklist of the vascular flora of Mount Tomah. pp. 63–85 in *The Mount Tomah book.* Second Edition (Mt Tomah Society and Royal Botanic Gardens Sydney).

Isely, D. (1998) *Native and naturalized Leguminosae (Fabaceae) of the United States (exclusive of Alaska and Hawaii)* (Monte L. Bean Life Science Museum, Brigham Young University: Provo, Utah).

Iwatsuki K., Boufford D.E. & Ohba H. (Eds) (2001) *Flora of Japan.* Volume 2b (Kodansha: Tokyo).

Iwatsuki K., Boufford D.E. & Ohba H. (Eds) (2006) *Flora of Japan.* Volume 2a (Kodansha: Tokyo).

Jacobs, S.W.L., Everett, J. & Torres, M.A. (1998) *Nassella tenuissima* recorded from Australia, a potential weed related to serrated tussock. *Telopea* 8: 41–46.

Jacobs, S.W.L., Whalley, R.D.B. & Wheeler, D.J.B. (2008) *Grasses of New South Wales.* 4th Edition (The University of New England: Armidale).

Jepson Online Interchange (2006+) The Jepson Online Interchange, California Floristics. University of California, Berkeley , http://ucjeps.berkeley.edu/interchange.html (viewed 9 August 2010).

Jessop, J.P. & Toelken, H.R. (Eds) (1986) *Flora of South Australia* Parts I–IV. 4th Edition (South Australian Government Printing Division: Adelaide).

Jones, G.N. (1940) A monograph of the genus *Symphoricarpos. Journal of the Arnold Arboretum* 21: 201–252.

Jørgensen, P.M. & León-Yánez, S. (Eds) (1999) *Catalogue of the vascular plants of Ecuador. Monographs in Systematic Botany from the Missouri Botanical Gardens.* Volume 75 (Missouri Botanical Gardens Press: St. Louis).

Keighery, G.J. (2005) New and noteworthy plant species recognised as naturalised in Western Australia. *Nuytsia* 15: 523–527.

Krüssmann, G. (1986) *Manual of cultivated broad-leaved trees and shrubs.* Volume 2, E–PRO (Batsford: London).

le Hardÿ de Beaulieu, A. (2003) *An illustrated guide to maples* (Timber Press: Portland).

Lindley, J. (1825) *Zephyranthes grandiflora. Edward's Botanical Register* 11 t. 902.

Liogier, H.A. (1988) *Descriptive flora of Puerto Rico and adjacent islands.* Volume 2 (Universidad de Puerto Rico: Río Piedras, Puerto Rico).

Liogier, H.A. (1995) *Descriptive flora of Puerto Rico and adjacent islands* Volume 4 (Universidad de Puerto Rico: Río Piedras, Puerto Rico).

Mackee, H.S. (1985) *Les plants introduites et cultivées en Nouvelle-Calédonie* (Muséum d'Histoire Naturelle: Paris).

Makino, T. (1964) *Makino's new illustrated flora of Japan* (The Hokuryukan Co. Ltd.: Tokyo).

Mathew, B. (1989) *The Iris* (Batsford books: London).

McCarthy, P.M. (Ed) (1998) *Flora of Australia*, Volume 48, Ferns, gymnosperms and allied groups (ABRS/CSIRO Publishing: Melbourne).

McDonald, W. (1986) Purple pigeon grass. Agfact P2.5.21 (Department of Agriculture: New South Wales).

McLaren, D.A., Whattam, M., Blood, K., Stajsic, V. & Hore, R. (1999) Mexican feather grass (*Nassella tenuissima*) a potential disaster for Australia. 12th Australian Weeds Conference: papers and proceedings. Eds A.C. Bishop, M. Boersma & C.D. Barnes, Hobart, Australia. 12–16 September 2004. pp. 658–662.

McMullen, C.K. (1999) *Flowering plants of the Galápagos* (Cornell University Press: Ithaca).

Meeuse, A.D.J. & Welman, A.E. (2000) *Flora of southern Africa.* Volume 28, Part 1 Convolvulaceae (National Botanical Institute: Pretoria).

Meyer, K. (2001) Revision of the southeast Asian genus *Melastoma* (Melastomataceae). *Blumea* 46: 351–398.

Mitchell, A. (1988) *A field guide to the trees of Britain and northern Europe* (Collins: London).

Mooney, H.A. & Hobbs, R.J. (Eds) (2000) *Invasive species in a changing world* (Island Press: Washington, D.C.).

Moore, L.B. & Edgar, E. (1970) *Flora of New Zealand.* Volume 2 (A.R. Shearer, Government Printer: Wellington).

Morin, N.R. (convening Ed.) (1997) *Flora of North America north of Mexico* Volume 3 (Oxford University Press: New York).

Morin, N.R. (convening Ed.) (2000) *Flora of North America north of Mexico* Volume 22 (Oxford University Press: New York).

Morin, N.R. (convening Ed.) (2002) *Flora of North America north of Mexico* Volume 24 (Oxford University Press: New York).

Morin, N.R. (convening Ed.) (2003a) *Flora of North America north of Mexico* Volume 4 (Oxford University Press: New York).

Morin, N.R. (convening Ed.) (2003b) *Flora of North America north of Mexico* Volume 25 (Oxford University Press: New York).

Morin, N.R. (convening Ed.) (2006a) *Flora of North America north of Mexico.* Volume 19 (Oxford University Press: New York).

Morin, N.R. (convening Ed.) (2006b) *Flora of North America north of Mexico.* Volume 21 (Oxford University Press: New York).

Norman, E.M. (2000) Buddlejaceae. *Flora Neotropica Monograph* 81 (The New York Botanical Garden: New York).

Ohwi, J. (1965) *Flora of Japan.* English Edition (Smithsonian Institution: Washington, D.C.).

Pías, B. & Guitián, P. (2006) Breeding system and pollen limitation in the masting tree *Sorbus aucuparia* L. (Rosaceae) in the NW Iberian Peninsula. *Acta Oecologica* 29: 97–103.

PlantNET (1999+) Plant Information Network of the Botanic Gardens Trust, http://plantnet.rbgsyd.nsw.gov.au/ (viewed: 9 August 2010).

Poole, A.L. & Adams, N.M. (1990) *Trees and shrubs of New Zealand* (DSIR Publishing: Wellington).

Pyšek, P., Richardson, D.M., Rejmánek, M., Webster, G.L., Williamson, M. & Kirschner, J. (2004) Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. *Taxon* 53: 131–143.

Rejmánek, M. & Richardson, D.M. (1996) What attributes make some plant species more invasive. *Ecology* 77: 1655–1661.

Richards, J. (1993) *Primula* (Timber Press: Portland).

Richardson, D.M., Pyšek, P., Rejmánek, M., Barbour, M.G., Panetta, F.D. & West, C.J. (2000) Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* 6: 93–107.

Rickett, H.W. (1966) *Wildflowers of the United States. The northeastern states.* Volume 1 part 2 (McGraw-Hill: New York).

Roy, B., Popay, I., Champion, P., James, T. & Rahman, A. (1998) *An illustrated guide to common weeds of New Zealand* (New Zealand Plant Protection Society: Lincoln University).

Rozefelds, A.C.F., Cave, L., Morris, D.I. & Buchanan, A.M. (1999) The weed invasion in Tasmania since 1970. *Australian Journal of Botany* 47: 23–48.

Rudman, T. & Goninon, C. (2002) Eradication case history, *Hieracium pilosella* L. ssp. *nigrescens* (Fr.) Nägeli & Peter in Tasmania. Proceedings of the Thirteenth Australian Weeds Conference. Eds H. Spafford Jacob, J. Dodd & J.H. Moore, Perth, Australia. 8–13 September 2002. pp. 304–306.

Salmon, J.T. (1980) *The native trees of New Zealand* (Reed: Wellington).

Sharp, D. & Simon, B.K. (2002) *AusGrass: Grasses of Australia.* CD–ROM, Version 1.0 (Australian Biological Resources Study, Canberra, and Environmental Protection Agency: Queensland).

Simberloff, D., Nuñez, M.A., Ledgard, N.J., Pauchard, A., Richardson, D.M., Sarasola, M., van Wilgen, B.W., Zalba, S.M., Zenni, R.D., Bustamante, R., Peña, E. & Ziller, S.R. (2010) Spread and impact of introduced conifers in South America: lessons from other southern hemisphere regions. *Austral Ecology* 35: 489–504.

Smith, A.C. (1985) *Flora vitiensis nova a new flora of Fiji (spermatophytes only)* 3 (Pacific Tropical Botanic Garden: Lawai, Kauai, Hawaii).

Spencer, R. (Ed.) (1997) *Horticultural flora of south-eastern Australia. Volume 2. Flowering Plants. Dicotyledons. Part 1* (University of New South Wales Press: Sydney).

Spencer, R. (Ed.) (2002a) *Horticultural flora of south-eastern Australia. Volume 3. Flowering Plants. Dicotyledons. Part 2* (University of New South Wales Press: Sydney).

Spencer, R. (Ed.) (2002b) *Horticultural flora of south-eastern Australia. Volume 4. Flowering Plants. Dicotyledons. Part 3* (University of New South Wales Press: Sydney).

Spencer, R. (Ed.) (2005) *Horticultural flora of south-eastern Australia. Volume 5. Flowering Plants. Monocotyledons.* (University of New South Wales Press: Sydney).

Stace, C. (1997) *New flora of the British Isles.* 2nd Edition (Cambridge University Press: Cambridge).

Stace, H.M. & Edye, L.A. (Eds) (2000) *The biology and agronomy of Stylosanthes* (Academic Press: Sydney).

Stuart, D.D. (2006) *Buddlejas* (Timber Press: Portland, Oregon).

Tabak, N.M. & von Wettberg, E. (2008) Native and introduced jewelweeds of the northeast. *Northeastern Naturalist* 15: 159–176.

Tassin, J., Rivière, J.-N., Cazanove, M. & Bruzzese, E. (2006) Ranking of invasive woody plant species for management on Réunion Island. *Weed Research* 46: 388–403.

Thompson, I.R. (2007) A taxonomic treatment of tribe Anthemideae (Asteraceae) in Australia. *Muelleria* 25: 21–58.

't Mannetje (1977) A revision of varieties of *Stylosanthes guianensis* (Aubl.) Sw. *Australian Journal of Botany* 25: 347–362.

Tutin, T.G., Burges, N.A., Chater, A.O., Edmondson, J.R., Heywood, V.H., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, D.A. (Eds) (1993) *Flora Europaea.* Volume 1. Revised (Cambridge University Press: London).

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, D.A. (Eds) (1968) *Flora Europaea.* Volume 2 (Cambridge University Press: London).

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, D.A. (Eds) (1972) *Flora Europaea*. Volume 3 (Cambridge University Press: London).

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, D.A. (Eds) (1976). *Flora Europaea*. Volume 4 (Cambridge University Press: London).

Tutin, T.G., Heywood, V.H., Burges, N.A., Moore, D.M., Valentine, D.H., Walters, S.M. & Webb, D.A. (Eds) (1980) *Flora Europaea*. Volume 5 (Cambridge University Press: London).

USDA, NRCS (1995+) The PLANTS database, National Plant Data Center, Greensboro, NC 27401 USA. http://plants.usda.gov (viewed 9 August 2010).

van der Walt, J.J.A. (1985). A taxonomic revision of the type section of *Pelargonium* L'Hérit. *Bothalia* 15: 345–385.

Verloove, F. (2005). A synopsis of *Jarava* Ruiz & Pav. and *Nassella* E. Desv. (*Stipa* L. s.l.) (Poaceae: Stipeae) in southwestern Europe. *Candollea* 60: 97–117.

Wagner, W.L., Herbst, D.R. & Sohmer, S.H. (1999) *Manual of the flowering plants of Hawai'i*. Volumes 1 & 2. Revised Edition (University of Hawai'i Press: Honolulu).

Walsh, N.G. & Entwisle, T.J. (Eds) (1994) *Flora of Victoria*. Volume 2 (Inkata Press: Melbourne).

Walsh, N.G. & Entwisle, T.J. (Eds) (1996) *Flora of Victoria*. Volume 3 (Inkata Press: Melbourne).

Walsh, N.G. & Stajsic, V. (2007) *A census of the vascular plants of Victoria*. 8th Edition (National Herbarium of Victoria: Melbourne).

Webb, C.J., Sykes, W.R. & Garnock-Jones, P.J. (1988) *Flora of New Zealand*. Volume 4 (Botany Division DSIR: Christchurch).

Webb, C.J., Sykes, W.R., Garnock-Jones, P.J. & Brownsey, P.J. (1995) Checklist of dicotyledons, gymnosperms, and pteridophytes naturalised or casual in New Zealand: additional records 1988–1993. *New Zealand Journal of Botany* 33: 151–182.

Williams, M.C. & Wardle, G.M. (2009). *Pinus radiata* invasion in New South Wales: the extent of spread. *Plant Protection Quarterly* 24: 146–156.

Wilson, A. (Ed.) (1994) *Flora of Australia*. Volume 49, Oceanic islands 1 (Australian Government Publishing Service: Canberra).

Wilson, A. (Ed.) (1999) *Flora of Australia*. Volume 17B, Proteaceae *Hakea* to *Dryandra* (ABRS/CSIRO: Melbourne).

Wilson, A. (Ed.) (2009) *Flora of Australia*. Volume 44A, Poaceae 2 (ABRS/CSIRO: Melbourne).

Wilson, P.G. & Rowe, R. (2008). A revision of the Indigofereae (Fabaceae) in Australia. 2. *Indigofera* species with trifoliate and alternately pinnate leaves. *Telopea* 12: 293–307.

World Checklist of Monocotyledons (2006+). World Checklist of Monocotyledons, The Board of Trustees of the Royal Botanic Gardens, Kew. http://apps.kew.org/wcsp/home.do (viewed 27 October 2010).

Wu, Z. & Raven, P.H. (Eds) (2000) *Flora of China. Volume 24 (Flagellariaceae through Marantaceae)* (Science Press: Beijing, and Missouri Botanical Garden Press: St Louis).

Wu, Z. & Raven, P.H. (Eds) (2002) *Flora of China. Volume 24 Illustrations (Flagellariaceae through Marantaceae)* (Science Press: Beijing, and Missouri Botanical Garden Press: St Louis).

Wu, Z. & Raven, P.H. (Eds) (2003) *Flora of China*. Volume 5 (Missouri Botanical Garden Press: St Louis).

Wu, Z.Y., Raven, P.H. & Hong, D.Y. (Eds) (2005) *Flora of China. Volume 14 (Apiaceae through Ericaceae)* (Science Press: Beijing, and Missouri Botanical Garden Press: St Louis).

Wu, Z., Raven, P.H. & Hong, D. (Eds) (2008) *Flora of China. Volume 11 (Oxalidaceae through Aceraceae)* (Missouri Botanical Garden Press: St Louis).

Wunderlin R.P. & Hansen, B.F. (1996+) Atlas of Florida vascular plants, University of South Florida, Tampa, Florida, USA, http://www.plantatlas.usf.edu/ (viewed 9 August 2010).

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Appendix 1. Summary information on the 174 species in this paper or in the two previous papers in the series (Hosking et al. 2003, Hosking et al. 2007). Name, Family, Growth Form, First Record, Botanical Regions, Place of Origin, Introduction Source, Weed Potential in NSW, and *Cunninghamia* volume are provided.

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Abrus precatorius subsp. *africanus*	Fabaceae (Faboideae)	Vine	14 Mar 2001	NC	tropical Africa and Indian Ocean islands	Ornamental	Moderate	10(1): 162 & 8(2): 183 incorrectly as *Abrus precatorius* subsp. *precatorius*
Abutilon pictum	Malvaceae (Malvoideae)	Shrub	17 Sep 2003	CC	South America	Ornamental	Minor	10(1): 155
Acacia pulchella var. *pulchella*	Fabaceae (Mimosoideae)	Shrub	27 Sep 2000	CT	south western Western Australia	Ornamental	Moderate	8(2): 183
Acanthus mollis	Acanthaceae	Herb	25 Feb 2002	CC & CT	southern Europe, northern Africa & western Asia	Ornamental	Minor	10(1): 145
Acer palmatum	Aceraceae	Tree	31 Mar 2004	CT	South Korea & Japan	Ornamental	Minor	12(1)
Acer saccharinum	Aceraceae	Tree	9 Feb 2004	CT	eastern Canada to Guatemala	Ornamental	Minor	12(1)
Achillea filipendula	Asteraceae	Herb	8 Feb 1996	ST	central and western Asia	Ornamental	Minor	12(1)
Acokanthera oblongifolia	Apocynaceae	Shrub/Tree	May 2003	NC	South Africa (eastern Cape Province, Natal) & southern Mozambique	Ornamental	Minor	12(1)
Aesculus indica	Hippocastanaceae	Tree	23 Mar 2003	CT	eastern Afghanistan, northern India, Nepal and northern Pakistan	Ornamental	Minor	10(1): 154
Agapanthus paraecox subsp. *orientalis*	Alliaceae	Herb	23 Apr 2002	CT	South Africa	Ornamental	Moderate	10(1): 142
Agave vivipara	Agavaceae	Herb	28 Nov 2001	NC	North America	Ornamental	Minor	8(2): 177
Ajuga reptans	Lamiaceae	Herb	25 Nov 2002	CT	Europe, western Asia and northern Africa	Ornamental	Minor	10(1): 154
Alnus glutinosa	Betulaceae	Tree	10 Apr 1999	ST & CT	Europe, western Asia & northern Africa	Ornamental	Moderate? (Major in New Zealand)	8(2): 179
Anemone hupehensis var. *japonica*	Ranunculaceae	Herb	14 Apr 2004	CT	Horticulture, derived from Chinese *A. hupehensis*	Ornamental	Minor	12(1)
Anigozanthos flavidus	Haemorodoraceae	Herb	20 Nov 2003	SC	south western Western Australia	Ornamental	Moderate	10(1): 144
Aquilegia vulgaris	Ranunculaceae	Herb	21 Nov 2003	CT	Europe & north western Africa	Ornamental	Minor	10(1): 157
Arbutus unedo	Ericaceae (Arbutoideae)	Tree	27 Mar 2003	CT & ST	southern Europe, northern Africa & Turkey	Ornamental	Moderate	10(1): 152

Name	Family	Growth Form	First Record	Botanical Regions[1]	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Athertonia diversifolia	Proteaceae	Tree	14 Mar 2003	NC	northern Queensland	Ornamental	Minor	10(1): 157
Berberis aquifolium	Berberidaceae	Shrub	6 Oct 1947	NT, CT, ST & SWS	British Columbia to northern California	Ornamental	Moderate but major in Europe	12(1)
Berberis thunbergii	Berberidaceae	Shrub	6 Oct 2000	CT	Japan	Ornamental	Moderate? (Major in North America)	8(2): 179
Bergenia x schmidtii	Saxifragaceae	Herb	20 Aug 2003	CC & CT	Horticulture	Ornamental	Minor	10(1): 160
Bidens aurea	Asteraceae	Herb	1956	CC	southern Arizona to Guatemala	Ornamental	Minor	12(1)
Bromus catharticus subsp. *stramineus*	Poaceae	Grass	17 Jan 1973	CT & ST	Argentina & Chile	Unknown	Moderate	10(1): 144
Brugmansia suaveolens	Solanaceae	Shrub	21 Nov 1992	NC	Peru, Bolivia & Brazil	Ornamental	Minor	12(1)
Brugmansia x candida	Solanaceae	Shrub	29 Nov 1980	CC	Ecuador & Peru	Ornamental	Minor	12(1)
Bryophyllum daigremontianum	Crassulaceae	Herb	2 Sep 2003	NWP	Madagascar	Ornamental	Minor	10(1): 151
Bryophyllum x houghtonii	Crassulaceae	Herb	24 Jul 1970	NC, CC, NWS & NWP	Hybrid developed in USA	Ornamental	Major	8(2): 181 as *Bryophyllum daigremontianum* x *B. delagoense*
Bryophyllum fedtschenkoi	Crassulaceae	Herb	8 Jul 2002	NWP	Madagascar	Ornamental	Minor	10(1): 151
Buddleja dysophylla	Scrophulariaceae	Shrub	21 Jun 1953	CC	eastern South Africa to Tanzania & Zaïre	Ornamental	Minor	12(1)
Callisia fragrans	Commelinaceae	Herb	21 Nov 2000	NC & CC	Horticulture	Ornamental	Minor	8(2): 177–178
Calyptocarpus vialis	Asteraceae	Herb	13 Aug 2002	NC, CC & NWP	Mexico, El Salvador & Honduras	Unknown	Moderate	10(1): 147
Ceiba speciosa	Malvaceae (Bombacoideae)	Tree	14 Mar 2003	NC	Argentina, Brazil & Paraguay	Ornamental	Minor	10(1): 148–149
Celtis sinensis	Ulmaceae	Tree	10 Mar 1986	NC & NT	China, Korea & Japan	Ornamental	Major	8(2): 185
Cereus uruguayanus	Cactaceae	Shrub/Tree	25 Nov 2003	NWS & NWP	North America	Ornamental	Minor	10(1): 149
Cestrum x cultum	Solanaceae	Shrub	21 Aug 2003	CC	Horticulture	Ornamental	Minor	10(1): 160
Chamaecyparis lawsoniana	Cupressaceae	Tree	3 Dec 2003	CT	USA	Ornamental	Minor	10(1): 140–141
Chamaesyce ophthalmica	Euphorbiaceae	Herb	21 Nov 2000	NC & NT	south eastern USA to northern Argentina & Paraguay	Unknown	Minor	8(2): 182 & 10 (1): 162
Cistus salviifolius	Cistaceae	Shrub	2 Nov 1988	ST	southern Europe, northern Africa and Tunisia	Ornamental	Minor	10(1): 150
Clematis montana	Ranunculaceae	Climber	26 Nov 2002	CT	Afghanistan, India, Bhutan and China	Ornamental	Moderate	10(1): 157
Convolvulus farinosus	Convolvulaceae	Herb	Feb 2003	CC	Eritrea & Ethiopia to South Africa, Madagascar & Mascarene Islands	Unknown	Moderate	12(1)
Coprosma x cunninghamii	Rubiaceae	Shrub	30 Sep 2003	CT	New Zealand	Ornamental	Minor	10(1): 159
Coprosma robusta	Rubiaceae	Shrub/Tree	24 Mar 2003	CT	New Zealand	Ornamental	Moderate	10(1): 159–160

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Cordyline australis	Asparagaceae (Lomandroideae)	Tree	26 Nov 2004	CT	New Zealand	Ornamental	Minor	12(1)
Coriandrum sativum	Apiaceae	Herb	22 Jun 2000	NWS, CWS & NWP	possibly Mediterannean region to south western Asia	Spice	Minor	12(1)
Cornus capitata	Cornaceae	Tree	3 Dec 2003	ST	China, Bhutan, India (Assam, Punjab) and Myanmar	Ornamental	Moderate	10(1): 150–151
Corymbia citriodora	Myrtaceae	Tree	15 Mar 1963	CC	Queensland	Ornamental	Moderate	12(1)
Cotoneaster microphyllus	Rosaceae (Spiraeoideae)	Shrub	23 Feb 2000	CT & ST	China, Bhutan, India & Nepal	Ornamental	Minor	10(1): 162–163 & 8(2): 184 incorrectly as *Cotoneaster ?horizontalis*
Cotoneaster symondsii	Rosaceae (Spiraeoideae)	Shrub	28 Nov 2002	CT	northern India, Bhutan and Nepal	Ornamental	Moderate	10(1): 158 as *Cotoneaster simonsii*
Cotoneaster x watereri	Rosaceae (Spiraeoideae)	Shrub	26 Nov 2002	CT	Hybrid developed in cultivation	Ornamental	Minor	10(1): 158
Crassula ericoides subsp. *ericoides*	Crassulaceae	Shrub	<Mar 1998	CT	coastal areas of South Africa	Ornamental	Minor	12(1)
Crinum moorei	Amaryllidaceae	Herb	16 Mar 1997	SC & CT	South Africa	Ornamental	Minor	10(1): 142
Crotalaria retusa	Fabaceae (Faboideae)	Shrub	2 Apr 2001	NC	tropical & subtropical Africa, Asia & northern Australia	Ornamental	Minor	12(1)
Cupressus arizonica	Cupressaceae	Tree	17 Mar 1999	CT & ST	USA (Arizona, California, New Mexico) & Mexico (Chihuahua, Sonora)	Ornamental	Minor	8(2): 176
Cupressus lusitanica	Cupressaceae	Tree	9 Feb 1991	CT	Mexico, El Salvador, Guatemala & Honduras	Ornamental	Minor	10(1): 141
Cylindropuntia fulgida var. *mamillata*	Cactaceae	Shrub	18 Sep 2000	NWP & NFWP	Arizona	Ornamental	Moderate	10(1): 149
Cylindropuntia kleiniae	Cactaceae	Shrub	19 Sep 2000	NWP	USA (southern New Mexico, south western Texas) & nothern Mexico	Ornamental	Minor	10(1): 161 & 8(2): 180 incorrectly as *Cylindropuntia arbuscula*
Cylindropuntia leptocaulis	Cactaceae	Shrub	19 Sep 2000	NWS & NWP	north western Mexico & adjoining areas of the USA	Ornamental	Minor	8(2): 180 & 10(1): 161
Cylindropuntia prolifera	Cactaceae	Shrub	24 Apr 1993	NWP & NFWP	California & Baja California	Ornamental	Moderate	10(1): 150–151
Cylindropuntia rosea	Cactaceae	Shrub	18 Sep 2000	NWS & NWP	Mexico	Ornamental	Moderate to Major	10(1): 161–162 & 8(2): 181 incorrectly as *Cylindropuntia tunicata*
Cylindropuntia spinosior	Cactaceae	Shrub	9 May 2000	NWP & NFWP	USA (Arizona, New Mexico) & Mexico (Chihuahua, Sonora)	Ornamental	Minor	8(2): 180–181 & 10(1): 162
Cylindropuntia tunicata	Cactaceae	Shrub	25 Nov 2003	NWP	southern USA, northern Mexico & Cuba	Ornamental	Moderate to Major	10(1): 150 & incorrectly listed in 8(2): 180
Cyperus prolifer	Cyperaceae	Herb	28 Oct 1979	NC	southern USA, northern Mexico & Cuba	Ornamental	Moderate	12(1)
Cyperus teneristolon	Cyperaceae	Herb	10 Mar 2000	CT	eastern & southern Africa	Unknown	Moderate	8(2): 178
Desmanthus virgatus	Fabaceae (Faboideae)	Shrub	May 2002	NWP	Texas to Argentina & Uruguay	Pasture	Moderate	10(1): 153

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Deutzia crenata	Hydrangeaceae	Shrub	19 Nov 1985	CT	Japan	Ornamental	Major	8(2): 183–184
Drosanthemum candens	Acanthaceae	Shrub	22 Jan 1992	SC	South Africa	Ornamental	Minor	10(1): 147
Echinochloa polystachya	Poaceae	Grass	14 May 2001	NC	southern USA to Argentina & Uruguay	Pasture	Moderate to Major	12(1)
Elaeagnus umbellata	Elaeagnaceae	Shrub	27 Sep 2003	CT	Afghanistan to China, Korea & Japan	Ornamental	Minor but major in the USA	10(1): 151–152
Eragrostis trichophora	Poaceae	Grass	14 Apr 2003	NWS & NWP	southern Africa	Unknown	Moderate to Major	10(1): 144–145
Erica arborea	Ericaceae (Ericoideae)	Tree	6 Oct 2000	CT	southern Europe, Asian Turkey and central to northern Africa	Ornamental	Moderate	8(2): 182
Erica glandulosa	Ericaceae (Ericoideae)	Shrub	17 May 2000	CT	South Africa (Cape Province)	Ornamental	Minor	8(2): 182
Eugenia uniflora	Myrtaceae	Shrub/Tree	8 Mar 2000	NC	northern Argentina, Bolivia, Brazil, Paraguay & Uruguay	Fruit	Moderate to Major	12(1)
Eupatorium lindleyanum	Asteraceae	Herb	<1865	NC & NT	China, Japan, Taiwan & Philippines	Ornamental	Minor	10(1): 147–148
Ficus carica	Moraceae	Tree	9 Dec 1993	CC, NWS, CWS & SWS	southern Europe, northern Africa and Asia	Fruit tree	Minor	12(1)
Geranium robertianum	Geraniaceae	Herb	21 Nov 2000	CC & CT	Europe, Asia & north Africa	Ornamental	Moderate	8(2): 183
Gibasis pellucida	Commelinaceae	Herb	5 Dec 2003	CC	Mexico	Ornamental	Minor	10(1): 143
Gladiolus dalenii	Iridaceae	Herb	11 Jan 2004	NC, CC, SC & CT	Senegal to Sudan, Eritrea, South Africa, Saudi Arabia & Yemen	Ornamental	Moderate	12(1)
Gladiolus hybrid (with *G. dalenii* strain dominating)	Iridaceae	Herb	22 Jan 2004	CT	Horticulture	Ornamental	Minor	12(1)
Glechoma hederacea	Lamiaceae	Herb	28 Oct 1973	CC & NT	Europe & Asia	Ornamental	Moderate	10(1): 154
Hakea laurina	Proteaceae	Shrub/Tree	May 1969	NT & SWS	south western Western Australia	Ornamental	Minor	12(1)
Hemerocallis fulva var. *fulva*	Xanthorrhoeaceae	Herb	19 Jan 2004	CC & CT	probably China & Japan	Ornamental	Minor	12(1)
Hesperis matronalis	Brassieaceae	Herb	17 Jan 1989	CT	southern Europe to western Siberia	Ornamental	Minor	10(1): 149
Hieracium aurantiacum subsp. *carpathicola*	Asteraeeae	Herb	17 Dec 2003	ST	Europe	Ornamental	Moderate to Major	10(1): 148
Hieracium murorum	Asteraceae	Herb	Nov 1998	CT	Europe & western Asia	Unknown	Minor	8(2): 179
Hieracium pilosella	Asteraceae	Herb	1992	ST	Europe & Asia	Ornamental	Major	12(1)
Hippeastrum puniceum hybrid	Amaryllidaceae	Herb	23 Nov 2000	NC	Horticulture	Ornamental	Minor	8(2): 177
Hyacinthoides non-scripta	Hyacinthaceae	Herb	5 Oct 2000	CT	western Europe	Ornamental	Minor	8(2): 178
Hydrangea macrophylla	Hydrangeaceae	Shrub	12 Sep 1999	NT & CT	Asia (Himalayas to South Korea & Japan)	Ornamental	Minor	12(1)
Hydrocleys nymphoides	Limnocharitaceae	Herb	Nov 1957	NC, CC & SWS	Guatemala to Argentina	Ornamental	Moderate	12(1)
Hymenachne amplexicaulis	Poaceae	Grass	14 Apr 2004	NC	Mexico to Paraguay	Pasture	Minor but major in more tropical areas	12(1)

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Hypericum calycinum	Hypericaceae	Shrub	13 Jan 2004	CT	northern Turkey & south eastern Bulgaria	Ornamental	Minor	12(1)
Hypericum kouytchense	Hypericaceae	Shrub	2 Feb 2000	CT	China (Guizhou)	Ornamental	Moderate	8(2): 181 & 10(2): 162
Hypericum patulum	Hypericaceae	Shrub	23 Feb 2000	CT	China (Guizhoa, Sichuan)	Ornamental	Minor	8(2): 181
Impatiens balfourii	Balsaminaceae	Herb	18 Apr 2004	CT	Himalayan India & Pakistan	Ornamental	Minor	12(1)
Indigofera spicata	Fabaceae (Faboideae)	Herb	Feb 2005	NC	Ethiopia to Central African Republic & South Africa, & to Yemen, Madagascar & Mauritius	Pasture	Moderate	12(1)
Inga edulis	Fabaceae (Mimosoideae)	Tree	25 Feb 2002	NC	Bolivia and Brazil to Colombia, Suriname and Venezuala	Ornamental and for fruit	Minor	10(1): 153–154
Iris laevigata	Iridaceae	Herb	16 Nov 2004	NC	China, Japan, Korea and eastern Russia	Ornamental	Minor	12(1)
Jacaranda mimosifolia	Bignoniaceae	Tree	27 Sep 1983	NC & CC	north western Argentina & southern Bolivia	Ornamental	Major	8(2): 180
Jasminum polyanthum	Oleaceae	Shrub	10 Sep 1981	NC, CC & CT	China (Guizhou, Sichuan, Yunnan)	Ornamental	Major	8(2): 184
Juglans ailantifolia	Juglandaceae	Tree	9 Feb 2004	CT	Japan & Russia (Sakhalin)	Ornamental & fruit tree	Minor	12(1)
Juglans regia	Juglandaceae	Tree	4 Mar 1994	ST	south eastern Europe to temperate Himalayas	Fruit tree	Minor	8(2): 184
Juniperus conferta	Cupressaceae	Shrub	25 Nov 2002	CT	Japan & Russia (Sakhalin)	Ornamental	Minor	10(1):141
Justicia betonica	Acanthaceae	Herb	22 Nov 2000	NC	Asia & tropical Africa	Ornamental	Minor	8(2): 178
Justicia caudata	Acanthaceae	Shrub	1 Oct 2002	NC	Mexico to South America	Ornamental	Minor	10(1): 145
Koelreuteria formosana	Sapindaceae	Tree	13 Mar 2001	NC	Taiwan	Ornamental	Moderate	8(2): 185
Lamium galeobdolon	Lamiaceae	Herb	26 Nov 2003	CT	Europe & western Asia	Ornamental	Minor	10(1): 154–155
Lathyrus tingitanus	Fabaceae (Faboideae)	Herb	21 Oct 1967	CC, SC & CT	south western Europe, north western Africa, Azores, Madeira and Canary Islands	Ornamental	Moderate	10(1): 153
Lilium lancifolium	Liliaceae	Herb	7 Feb 2004	CT	China, Japan & Korea	Ornamental	Minor	12(1)
Lygodium japonicum	Lygodiaceae	Fern	4 Aug 2000	CC	Japan & China to Pakistan, Sri Lanka & Papua New Guinea	Ornamental	Minor but major in south eastern USA	12(1)
Lysimachia fortunei	Primulaceae (Myrsinoideae)	Herb	13 Feb 2002	NT	Japan, Korea, China & Vietnam	Ornamental	Minor	10(1): 156–157
Maackia amurensis	Fabaceae (Faboideae)	Tree	27 Mar 2003	CT .	China, Japan, Korea and far eastern Russia	Ornamental	Minor	10(1): 153
Malephora crocea	Aizoaceae	Subshrub	Sep 1926	NWP	South Africa (Cape Province)	Ornamental	Minor	12(1)
Mauranthemum paludosum	Asteraceae	Herb	13 Nov 1988	CC & SC	Algeria to Libya & Spain	Ornamental	Minor	12(1)
Melastoma malabathricum	Melastomataceae	Shrub/Tree	1 May 1987	CC	western Indian Ocean Islands across southern Asia to Polynesia	Ornamental	Minor, possibly more of a problem in more tropical areas	12(1)

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Monstera deliciosa	Araceae	Herb	26 Mar 2002	NC & CC	southern North America	Ornamental	Minor	10(1): 142
Murdannia keisak	Commelinaceae	Herb	6 Mar 1974	CC	Asia	Ornamental	Minor	10(1): 143
Myagrum perfoliatum	Brassicaceae	Herb	1 Aug 2000	NWS	Europe & western Asia	Unknown	Major	8(2): 180
Nassella tenuissima	Poaceae	Grass	29 Sep 2004	ST & NWS	USA (New Mexico, Texas) & Mexico as well as Argentina & Chile	Ornamental	Major	12(1)
Odontonema tubaeforme	Acanthaceae	Shrub	25 Feb 2002	NC & CC	Mexico to Panama	Ornamental	Minor	10(1): 145–146
Oenothera biennis	Onagraceae	Herb	10 Apr 2001	CT	eastern USA & eastern Canada	Ornamental	Minor	8(2): 184
Oxalis vallicola	Oxalidaceae	Herb	3 Dec 2003	CT	Mexico	Ornamental	Minor	10(1): 155–156
Pelargonium quercifolium	Geraniaceae	Shrub	16 Nov 2004	NC	South Africa	Ornamental	Minor	12(1)
Phoenix canariensis	Arecaceae	Tree	26 Sep 1987	CC, NWS, CWS & SWS	Canary Islands	Ornamental	Major	10(1): 142–143
Phoenix reclinata	Arecaceae	Tree	17 Nov 2004	NC	tropical & subtropical Africa & Asia, & Indian Ocean islands	Ornamental	Moderate	12(1)
Phormium tenax	Xanthorrhoeaceae	Herb	1 Feb 2004	CC & CT	New Zealand	Ornamental	Minor	12(1)
Physostegia virginiana	Lamiaceae	Herb	14 Mar 1975	NC, CC & NT	Canada, USA and northern Mexico	Ornamental	Minor	10(1): 155
Pinus contorta	Pinaceae	Tree	5 Feb 2004	CT & ST	western Canada, western USA and north western Mexico	Ornamental	Major	12(1)
Pinus duraugensis	Pinaceae	Tree	13 Aug 2000	NT	northern Mexico	Ornamental	Minor	8(2): 176–177
Pinus halepensis	Pinaceae	Tree	14 Jan 1986	ST & SWS	southern Europe, western Asia & northern Africa	Forestry	Major	10(1): 161 & 8(2): 177 incorrectly as *Pinus nigra* var. *corsica*
Pinus patula	Pinaceae	Tree	15 Jun 2002	CC, NT & CT	Mexico	Ornamental	Major	10(1):141
Pittosporum eugenioides	Pittosporaceae	Tree	27 Mar 2003	CT	New Zealand	Ornamental	Moderate	10(1): 156
Pittosporum ralphii	Pittosporaceae	Shrub	25 Nov 2002	CT	New Zealand	Ornamental	Moderate	10(1): 156–157
Pittosporum tenuifolium	Pittosporaceae	Shrub/Tree	3 Dec 2003	CT	New Zealand	Ornamental	Minor	10(1): 156
Plectranthus ecklonii	Lamiaceae	Shrub	24 Apr 2002	CC	South Africa	Ornamental	Minor	10(1): 155
Podranea ricasoliana	Bignoniaceae	Vine	8 Dec 2004	CT	South Africa (eastern Cape Province, Kwazulu-Natal)	Ornamental	Minor	12(1)
Polygonatum x hybridum	Asparagaceae (Nolinoideae)	Herb	30 Oct 2004	CT	Horticulture	Ornamental	Minor	12(1)
Polypremum procumbens	Tetrachondraceae	Herb	28 Jun 1999	NC	south eastern and north central USA to Paraguay	Unknown	Minor	12(1)
Potentilla vesca	Rosaceae (Rosoideae)	Herb	26 Nov 2003	CT	northern hemisphere	Ornamental and for fruit	Minor	10(1): 158–159
Primula malacoides	Primulaceae (Primuloideae)	Herb	28 Aug 2004	CC	southern China & north eastern Myanmar	Ornamental	Minor	12(1)
Prunus campanulata	Rosaceae (Spiraeoideae)	Shrub/Tree	21 Aug 2003	CC	China, Japan & Taiwan	Ornamental	Minor	10(1): 157–158
Rhaphiolepis umbellata	Rosaceae (Spiraeoideae)	Shrub	12 Apr 1991	NC & SC	China, Taiwan, Japan & Korea (Quelpaert Island)	Ornamental	Minor	12(1)

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Rhododendron ponticum	Ericaceae (Ericoideae)	Shrub	25 Nov 2002	CT	south western Europe, south eastern Europe & western Asia	Ornamental	Moderate but Major in the British Isles & Ireland	10(1): 152
Romneya coulteri	Papaveraceae	Herb	2 Dec 1965	ST	south western California	Ornamental	Minor	12(1)
Romneya trichocalyx	Papaveraceae	Herb	7 Dec 1964	ST & SWS	south western California & north western Mexico	Ornamental	Minor	12(1)
Rosa luciae hybrids	Rosaceae (Rosoideae)	Shrub	1 Dec 1983	CC, CT, ST & NWS	China, Korea & Japan	Ornamental	Minor	10(1): 159
Rubus rugosus	Rosaceae (Rosoideae)	Shrub	26 Feb 2002	NC	India, Nepal and Sri Lanka to Malay Peninsula and Vietnam	Fruit	Minor	10(1): 159
Ruellia squarrosa	Acanthaceae	Shrub	7 Dec 1993	NC & CC	southern Mexico	Ornamental	Moderate	10(1): 146
Schinus terebinthifolius	Anacardiaceae	Tree	11 Jan 1995	NC, CC & ?NWP	Argentina, southern Brazil & eastern Paraguay	Ornamental	Major	8(2): 178–179
Scorpiurus muricatus	Fabaceae (Faboideae)	Herb	20 Oct 1999	CWS	Europe, Asia Minor and northern Africa	Pasture	Moderate	8(2): 183
Senna multijuga	Fabaceae (Caesalpinioideae)	Tree	14 Mar 2003	NC	Colombia to Peru, Bolivia and Brazil	Ornamental	Moderate	10(1): 152
Setaria incrassata	Poaceae	Grass	14 Feb 1995	NWS	Nigeria to Ethiopia & South Africa	Pasture	Moderate	12(1)
Sideritis lanata	Lamiaceae	Herb	21 Oct 1969	NWS	Greece, Bulgaria, Yugoslavia & Turkey	Unknown	Minor to Moderate	12(1)
Sorbus aucuparia	Rosaceae (Spiraeoideae)	Tree	7 Feb 2004	CT	Europe, Iceland & Asia	Ornamental	Minor	12(1)
Spartium junceum	Fabaceae (Faboideae)	Shrub	14 Jan 1986	SC, ST & NWS	southern Europe, northern Africa and western Asia	Ornamental	Minor	12(1)
Stapelia gigantea	Apocynaceae	Herb	3 Sep 2003	NWP	southern Africa	Ornamental	Moderate	10(1): 147
Stephanophysum longifolium	Acanthaceae	Herb	13 Mar 2003	NC	Brazil	Ornamental	Moderate to Major	10(1): 146
Strobilanthes anisophylla	Acanthaceae	Shrub	21 Aug 2003	CC	northern India & Bhutan	Ornamental	Minor	10(1): 146–147
Stylosanthes guianensis	Fabaceae (Faboideae)	Herb	4 Feb 2002	NC & NWS	southern Mexico to north eastern Argentina & Paraguay	Pasture	Moderate	12(1)
Stylosanthes humilis	Fabaceae (Faboideae)	Herb	1 Apr 2002	NC	Arizona to central Brazil	Pasture	Minor	12(1)
Symphoricarpos albus var. *laevigatus*	Caprifoliaceae	Shrub	7 Dec 2005	ST	south eastern Alaska to California	Ornamental	Minor	12(1)
Syzygium paniculatum	Myrtaceae	Shrub/Tree	30 Nov 2004	NWS	coastal New South Wales	Ornamental	Minor	12(1)
Tabebuia chrysotricha	Bignoniaceae	Tree	13 Mar 2003	NC	north eastern Argentina and Brazil	Ornamental	Minor	10(1): 148
Tabebuia impetiginosa	Bignoniaceae	Shrub/Tree	14 Mar 2003	NC	Mexico to Peru, north western Argentina, Paraguay & Brazil	Ornamental	Minor	10(1): 148
Tibouchina urvilleana	Melastomataceae	Shrub	23 May 1987	NC & CC	southern Brazil	Ornamental	Moderate	12(1)

Name	Family	Growth Form	First Record	Botanical Regions1	Place of Origin	Introduction Source	Weed Potential in NSW	*Cunninghamia* volume (part number): page(s)
Tillandsia usneoides	Bromeliaceae	Hanging epiphyte	20 Nov 2000	NC	south eastern USA to Argentina & Chile	Ornamental	Minor	8(2): 177
Tradescantia cerinthoides	Commelinaceae	Herb	8 Feb 2004	CC	northern Argentina & south eastern Brazil	Ornamental	Minor	12(1)
Tradescantia pallida	Commelinaceae	Herb	13 Nov 1985	CC & NWS	Mexico	Ornamental	Minor	10(1): 143–144
Triadica sebifera	Euphorbiaceae	Tree	3 May 2000	NC	China	Ornamental	Major	8(2): 182–183
Ulmus x hollandica	Ulmaceae	Tree	Jan 1973	CT & ST	Europe & Asia	Ornamental	Minor	10(1): 160
Utricularia sandersonii	Lentibulariaceae	Herb	Nov 2001	CT	South Africa (eastern Cape Province, Kwazulu-Natal)	Ornamental	Minor	12(1)
Viola riviniana	Violaceae	Herb	21 Dec 1983	CT & ST	Europe, northern Africa & Lebanon	Ornamental	Moderate	8(2): 185
Vitis vinifera	Vitaceae	Vine	10 Feb 1971	NC, CT, ST & NWS	Europe, western Asia and northern Africa	Fruit vine	Minor	8(2): 185–186
Washingtonia filifera	Arecaceae	Tree	10 Nov 2004	CWS	north western Mexico and south western USA	Ornamental	Minor	12(1)
Zephyranthes carinata	Amaryllidaceae	Herb	19 Oct 1987	NC	southern USA to Argentina	Ornamental	Minor	12(1)

Botanical Regions[1]: Botanical Divisions and Subdivisions of New South Wales as explained in Harden, G.J. (Ed.) (1990) *Flora of New South Wales* Volume 1 (University of New South Wales Press: Sydney); NC = North Coast, CC = Cental Coast, SC = South Coast, NT = Northern Tablelands, CT = Central Tablelands, ST = Southern Tablelands, NWS = North Western Slopes, CWS = Central Western Slopes, SWS = South Western Slopes, NWP = North Western Plains, SWP = South Western Plains, NFWP = North Far Western Plains, SFWP = South Far Western Plains

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